

Summer 8-2011

## Detection of Hydrogen in a Two-Phase Cryogen Flow Stream with Thermal Protection Design Configurations

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The University of Southern Mississippi

DETECTION OF HYDROGEN IN A TWO-PHASE CRYOGEN FLOW STREAM  
WITH THERMAL PROTECTION DESIGN CONFIGURATIONS

by

Anton Dmitrievitch Netchaev

A Thesis  
Submitted to the Graduate School  
of The University of Southern Mississippi  
in Partial Fulfillment of the Requirements  
for the Degree of Master of Science

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August 2011

## ABSTRACT

### DETECTION OF HYDROGEN IN A TWO-PHASE CRYOGEN FLOW STREAM WITH THERMAL PROTECTION DESIGN CONFIGURATIONS

by Anton Dmitrievich Netchaev

August 2011

All commercial liquid-propelled rockets use hydrogen as means to reach outer space. These rocket boosters are tested on the ground and use hydrogen as means of purging the remaining explosive gasses left in the test tanks. To conserve helium, a non-renewable resource, a test fixture was developed to characterize and test sensors that could improve the accuracy and response of the current system. By improving response time of the system, helium waste during the purge process can be minimized. The test fixture was constructed to simulate temperatures and pressures that are encountered at the testing facilities. The test fixture is outfitted with an array of sensors and valves to ensure proper simulation of the environment and safety of the personnel. Initial calibration and field verification on the hydrogen sensor were performed to ensure proper operation in an ideal environment and to prepare the sensor for testing outside the manufacturer-specified limits. Several configurations were implemented to optimally balance between response time and accuracy of the system. Implementation of a sensor array such as this would save money, time and helium wasted during each and every test.

## ACKNOWLEDGMENTS

I would like to thank my thesis director, Dr. Randy Buchanan, and all the other members on my committee for their unrelenting support and guidance as my mentors. I especially would like to thank Dr. Buchanan for providing me and my peers with interesting and ever-challenging projects and mentoring throughout our tenure at The University of Southern Mississippi. These projects not only further developed me as an engineer, but also introduced me to many test stand fabrication techniques previously unknown to me.

Special thanks to Dr. Dawoud who never gave up on me, even during lengthy setbacks. Dr. Dawoud has taught me everything I know about image processing and applications of this powerful tool in today's industry. These lessons came, not only in form of classes, but also as papers that were successfully published. These experiences will help my career as a Ph.D. student and as an engineer in the future.

I also wish to thank Dr. Zhou for challenging my mathematics knowledge and for always being there for his students. Last but not least, I would like to thank Dr. Paige Buchanan for giving me an opportunity to implement my skills in an entirely new field and apply them to evolving problems of polymer chemistry. I'm absolutely certain that without the complete dedication and support of these people and all of the faculty and staff at the Computing Department of The University of Southern Mississippi, I would not have completed this thesis.

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## LIST OF ABBREVIATIONS

Data Acquisition (DAQ)

Graphical User Interface (GUI)

Input Output (I/O)

Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW)

Lower Explosive Limit (LOL)

Micro-Electro-Mechanical-Systems (MEMS)

Metal Alloy, Oxide, Semiconductor (MOS)

National Aeronautics and Space Administration (NASA)

Nano-Electrical-Mechanical-Systems (NEMS)

National Instruments (NI)

Operational Amplifier (op-amp)

PCI eXtensions for Instrumentation (PXI).

Resistant Temperature Detectors (RTDs)

Small Business Innovation Research and Small Business Technology Transfer program  
(SBIR & STTR)

Solid State Relay's (SSR)

Universal Serial Bus (USB)

## CHAPTER I

### INTRODUCTION

To avoid potentially disastrous outcomes rockets need to be designed and extensively tested on the ground before they ever go to space. Since the development of the shuttle, every American rocket engine powered by liquid hydrogen was tested at John C. Stennis Space Center about seventy miles away from our university. After each and every test, the system had to be purged with helium to prevent hydrogen fires or even explosions. Helium is used for purging because it is the only gas that has lower freezing temperature than Hydrogen ( $H_2$ ) or Oxygen ( $O_2$ ), gasses used for the propulsion of spacecraft [4]. Existing technology at the testing facilities is wasteful, and at the current rate of inflation (2011 helium price will jump 15.8%), helium will be too expensive to use as a purge gas [17] [15]. Dr. Buchanan's background in cryogenic research and our close proximity to the test cite made us the perfect candidate for this research. Effective method for measuring  $H_2$  concentration during the purging process will save National Aeronautics and Space Administration (NASA) a significant amount of money. Automation of the purge process will save money for the company and save a nonrenewable resource for future generations.

## CHAPTER II

### REVIEW OF LITERATURE

#### H2 Test Stand Design Background

Webster's dictionary defines cryogenic as, an "environment of very low temperatures or relating to such" [7]. These extreme temperatures usually destroy a test stand, the sensors, and equipment it contains. Cryogenic temperatures require a special kind of material that does not crack or otherwise deform during rapid cooling. Stainless steel can be used in a cryogenic test stand due to its low linear expansion that would otherwise destroy the apparatus. Other materials also are suitable for this task, such as specially treated steel Teflon and others. Stainless steel was chosen for situations where the test stand has to be machined and produced in the most cost effective manner, whereas other materials either require molding or special treatment techniques to achieve the design needed for the fixture [6].

A test stand is device that is constructed to determine performance and characteristics of anything from parts to electronic components. Such stand must be designed to measure the relevant data for further analysis. A Cryogenic test stand is designed to test the effects of temperature. To measure the temperature and record it dynamically, one must use a data acquisition equipment and some sort of temperature sensor. There are a wide variety of different ways to measure cryogenic temperatures. For example, thermocouples types K and T can be used for this application [18]. A thermocouple consists of two different metals joined together to produce a minute current. This current can be measured and converted to temperature. Some other devices that can be used to measure cryogenic temperatures are Resistant Temperature Detectors

(RTDs) and integrated chips. By accurately measuring temperature throughout the test stand, one can characterize the sensor that was subjected to those temperatures.

### Pressure Sensors

Pressure sensor was also crucial for this experiment. The hydrogen sensor used for the experiment is highly sensitive to changes in pressure. To acquire accurate H<sub>2</sub> concentration pressure needs to be taken into account. The accuracy of the pressure sensor was directly related to the accuracy of the hydrogen reading. Pressure is defined as a force that is applied over an area [14]. To accurately measure force the sensor must have a known area of a material that changes a measurable property with application of force.

Capacitance pressure transducers are highly popular because of their ability to measure a wide range of pressures and relatively low cost. Initially these transducers were designed for measurement of pressures in low vacuum systems. Capacitance pressure transducers use a high frequency charge to measure the reactance of a diaphragm that was exposed to reference pressure and process pressure (Figure 1). The changes in pressure deflect the diaphragm which changed the capacitance measurement of the transducer. Stainless steel is the most common type of diaphragm material, but other alloys can be used for specific operational environments. A bridge circuit was used to detect the changes in capacitance. This sensor was limited by the design of the oscillator that produces high frequency signal to measure the reactance.

$$X_c = \frac{1}{2\pi fC}$$

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Equation 1: Reactance of a capacitor [14].

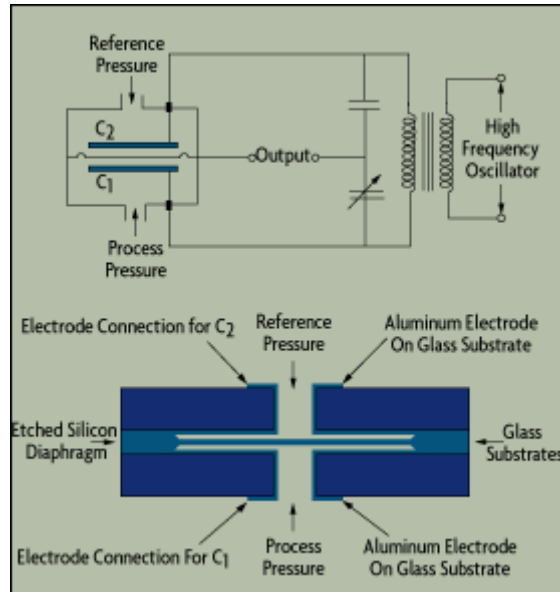


Figure 1. Capacitive pressure transducer [14].

Capacitance pressure transducers came with onboard circuitry that amplifies the output easy implementation into existing data acquisition systems [14].

A Piezoelectric pressure transducer was built on the principle that when a pressure is applied to a quartz crystal, a charge is generated across the crystal will be proportional to the force applied (Figure 2).

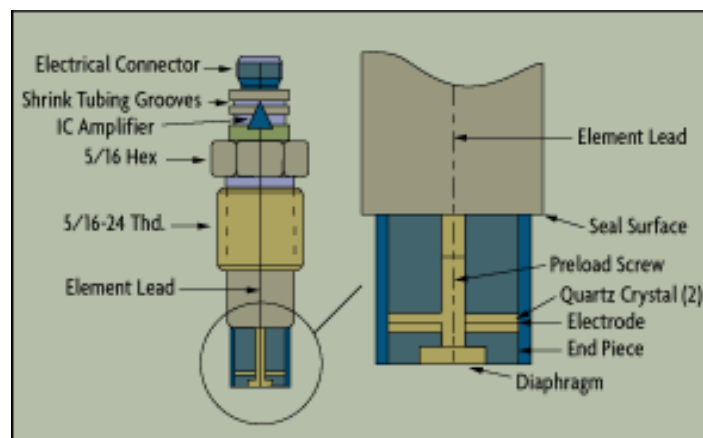


Figure 2. Piezoelectric pressure sensor [14].

These sensors only measured dynamic pressure environments because signal from the quartz crystal will decay rapidly in a static pressure environment. These sensors were used to measure pressure in rapidly changing environments where changes happen up too every millionth of a second [14].

Optical pressure transducers were designed to detect the effects of pressure on a dielectric mirrors that are attached to optical fiber wire. Light emitting diode is usually used as the light source that bounces light of dielectric mirrors that shift proportionally to the pressure applied (Figure 3).

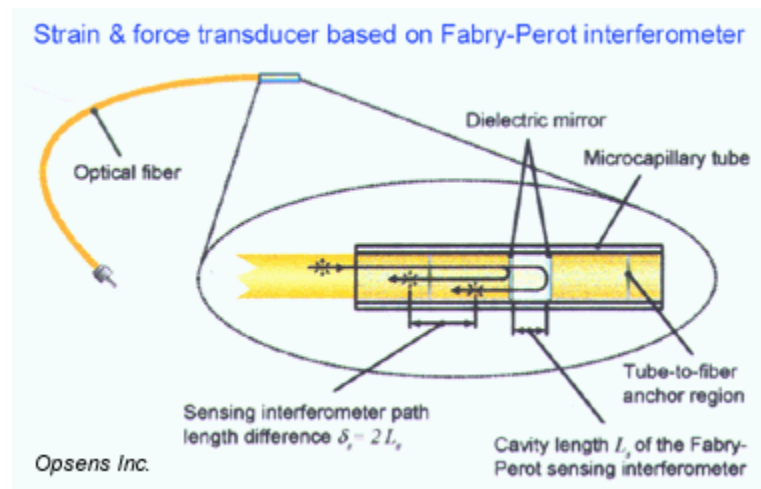


Figure 3. Optical pressure sensor [5].

These sensors were designed for maintenance free long-term continuous operation in hazardous environments. These sensors have wide operating ranges from 5psi to 60,000psi and usually have an accuracy of 0.1% Full Scale (FS) [5].

Strain gage pressure transducers operate similar to capacitive transducers, but use an elastic diaphragm that changes its resistivity based upon its displacement. These transducers are built with a low pressure side that contains a reference pressure and high pressure side that is exposed to the process (Figure 4).



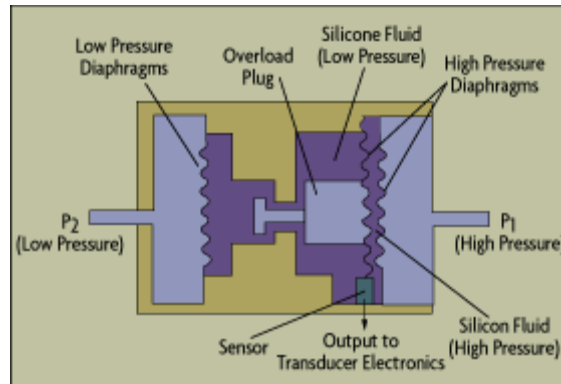


Figure 4. Strain Gage pressure transducer [14].

The transducer of this type has a small span and operates as a differential pressure sensor. Strain gage pressure transducers have to be calibrated often to maintain accuracy but are the most cost efficient way to measure pressure [14].

### Hydrogen Sensors

A Hydrogen sensor was a crucial part of this experiment. Therefore, the decision to buy a sensor was made only after analyzing several technologies that exist on the market today. A newcomer to hydrogen sensing is a sensor that combines Micro-Electro-Mechanical-Systems (MEMS) and Nano-Electrical-Mechanical-Systems (NEMS) in one sensor. This type of sensor used the same principle as catalytic bead sensor to oxidize the incoming gas hydrogen molecules. Microcatalytic oxidation of hydrogen was an exothermic reaction so it raised the temperature of the sensor which in turn increases the resistance of the element. Increase in resistivity was directly proportional to the hydrogen concentration in the gas stream [3]. This Sensor required  $O_2$  in the gas stream to operate, so it cannot be used during the hydrogen purging process.

Schottky diode hydrogen sensors have been around for a while and use a Metal Alloy, Oxide, Semiconductor (MOS) type structure (Figure 5).

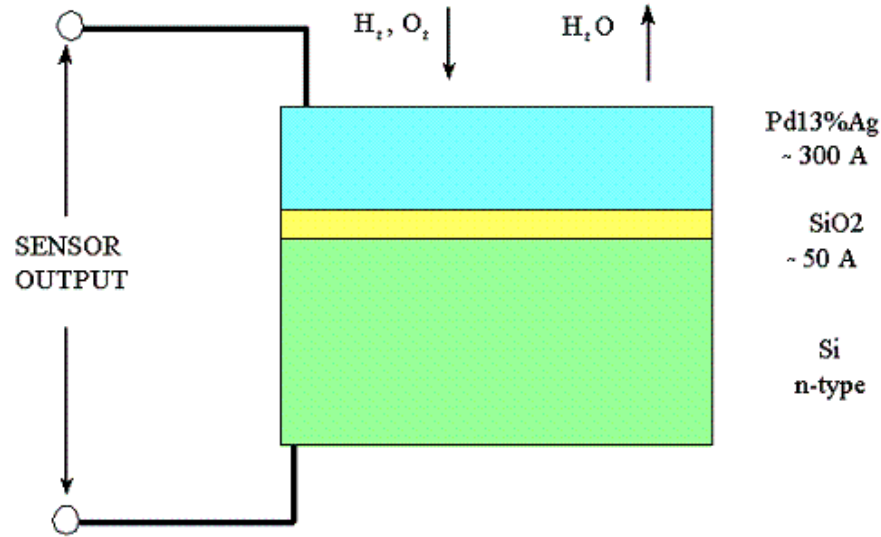


Figure 5. MOS structure of PD13%Ag shottky diode H<sub>2</sub> sensor [22].

This sensor operated on the principle that H<sub>2</sub> disassociates into atoms on the surface of the metal and migrates to the boundary between the metal and the silicon oxide layer.

This change in chemical structure of the diode changed the current and capacitance of the diode that could be correlated with hydrogen concentrations in the medium. This sensor did not require the presence of O<sub>2</sub> to operate but was highly sensitive to temperature fluctuations. This type of sensor came equipped with circuitry that compensates for temperature fluctuations so it was considered for implementation in test fixture design [22].

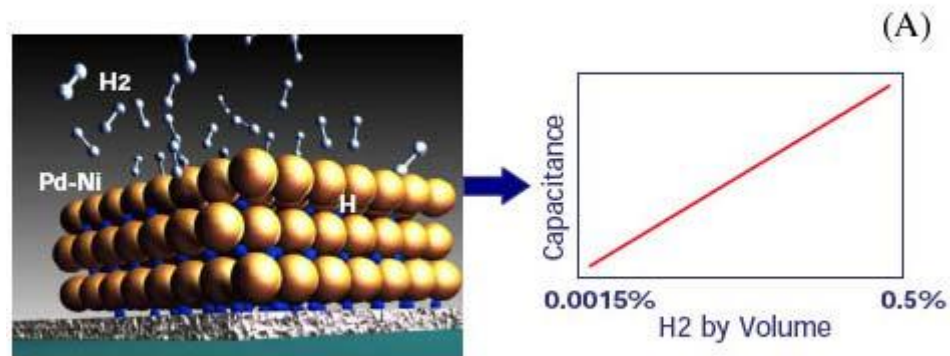
Thick-film H<sub>2</sub> Sensors were designed around a reaction between palladium and hydrogen which is thought to produce PdH<sub>2</sub> (may not be a true chemical compound).

This change in composition produced a compound with higher resistivity. So any exposure to hydrogen would increase the resistance of this type of sensor. This type of

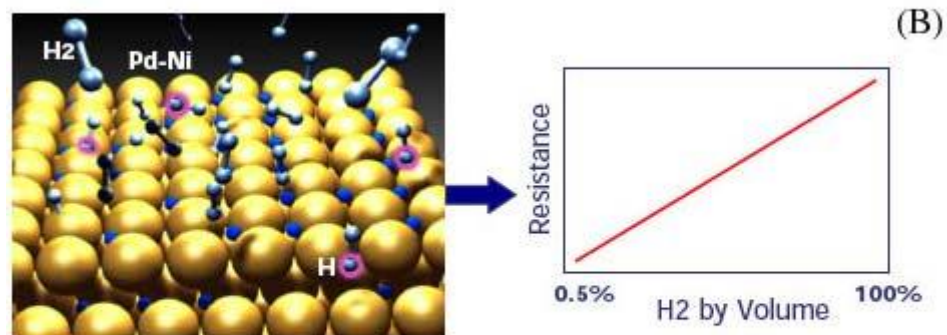
sensor has a response time measured in tens of milliseconds and it could have been used to detect the Lower Explosive Limit (LOL) of  $H_2$  which was around 40,000ppm. Thick-film sensors have a predefined lifespan based on how long it would take for hydrogen to react with all of the palladium at which point it would become unusable or maintenance would be required [1]. A sensor with a short lifespan was not suitable for the application.

**H<sub>2</sub> sensing process:**

- Step 1: Pd catalyzes  $H_2$  (molecular) into 2H (atomic)
- Step 2: Atomic hydrogen (H) absorbed into the Pd/Ni alloy lattice



Atomic hydrogen absorbed into the resistive sensor element is measured by a change in bulk resistivity.



Atomic hydrogen absorbed into the capacitive sensor element is measured by a change in charge density.

Figure 6. HCAP and HRES up-close [21].

The sensor chosen for the project contained two separate sensors, a Hydrogen Sensing Capacitor (HCAP) and a Hydrogen Sensing Resistor (HRES) both made out of thin molecular palladium lattice. Both of those sensing technologies used a thin film type of sensor. HCAP was capable of detecting hydrogen from 15ppm to 1500ppm and HRES from 0.5% to 100% concentrations. These thin film sensors were not dependent on the chemical interaction between palladium and hydrogen so they never deplete (Figure 6). H2Scan also used a temperature sensor to compensate for fluctuations in temperature of the medium [21]. H2Scan Hy-Optima 700 sensor was chosen for its advanced design, accuracy and ability to detect small changes in concentrations relatively fast  $T_{90} < 30\text{sec}$  over a wide temperature and pressure.

#### National Instrument Data Acquisition

National Instruments (NI) is a company that specializes in production of equipment for a variety of Data Acquisition (DAQ) tasks. NI also produces its own software for equipment which expedites the development of program for a wide array of DAQ projects. NI Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is a graphical programming interface also known as “G.” “G” language was named after the graphical user interface that replaces the traditional typed programs (C, C++, Java, Assembly...). LabVIEW uses so called Virtual Interface (VI) that consists of a block diagram and a front panel these contain all the programming and display portions of the program. Block diagram consists of blocks of code that are displayed as icons and connected by wires. This approach to programming has helped engineers and scientists in analyzing problems more effectively. Front panel, on the other hand, contains the Graphical User Interface (GUI) of the program. While programming, having an

automatically created GUI decreases the integration time of projects and helps troubleshoot any problems with the program throughout the developmental process. These and other features make this language unique but easy to learn [19].

## CHAPTER III

### EXPERIMENTAL APPARATUS

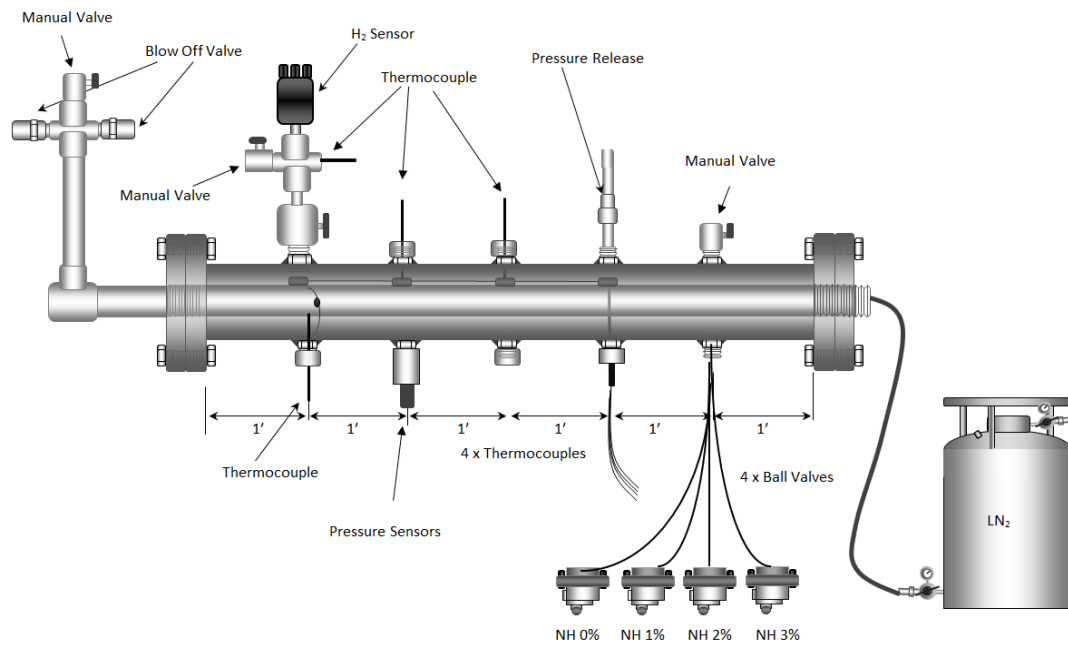
#### Test Fixture

The test fixture was developed and built specifically for NASA Small Business Innovation Research and Small Business Technology Transfer program (SBIR & STTR). This program has combined the innovation of universities and companies to solve many of the challenges that NASA encounters during its everyday operations. The fixture was designed to mimic the purge process of liquid hydrogen tanks; during this process it was crucial to acquire the hydrogen concentrations in the flow. The test apparatus consisted of a two concentric pipes, each six feet with internal diameters of one-half inch and two and a half inches (Figure 7).



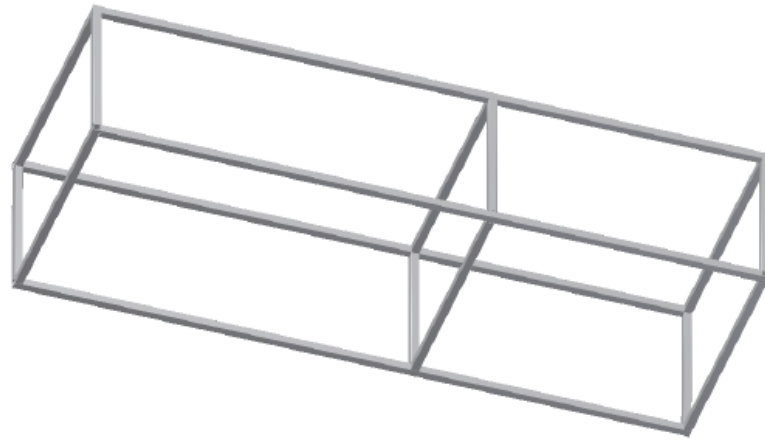
*Figure 7.* CAD drawing of the test fixture without sensors (Biju Bajracharya).

Schedule eighty 316 stainless steel was used to withstand extreme pressures. An H2Scan sensor was used in different configurations to detect the hydrogen concentrations in environment that had pressures up too 100psi and temperatures down to -20 Celsius. This environment was specifically chosen to emulate the field operating conditions of the sensor. To accurately monitor the environment and protect the sensor, the following instrumentation was used (Figure 8):



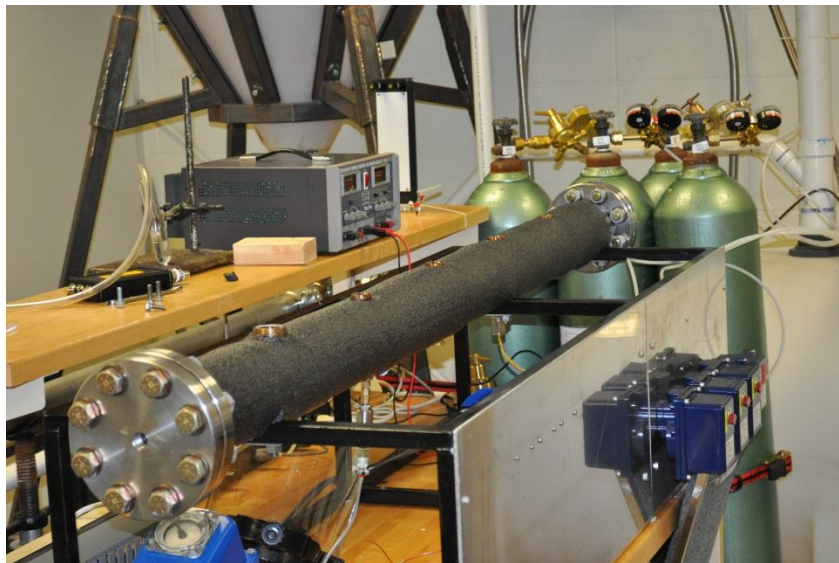
*Figure 8.* Test stand diagram.

The final design was constructed and implemented with support of Steve Allee inside school of computing cryogenics laboratory located inside Walker science building. The setup was secured to a stand that incorporated valve mounds and wire termination blocks. The stand was also designed in CAD software to ensure proper execution by the welding shop (Figure 9). The base was constructed out of one inch square tubing and professionally welded to ensure a solid platform for the test stand.



*Figure 9.* Base for test fixture (Biju Bajracharya).

Test stand was completely assembled and set up for testing on a pre-existing bench top (Figure 10). The final stage of construction was to secure all the instrumentation and wire the sensors to the appropriate data acquisition hardware. Final wiring diagram was created to ensure the results of testing can be replicated during further stages of STTR funding (Figure 11).



*Figure 10.* Assembled stand and test fixture without instrumentation.



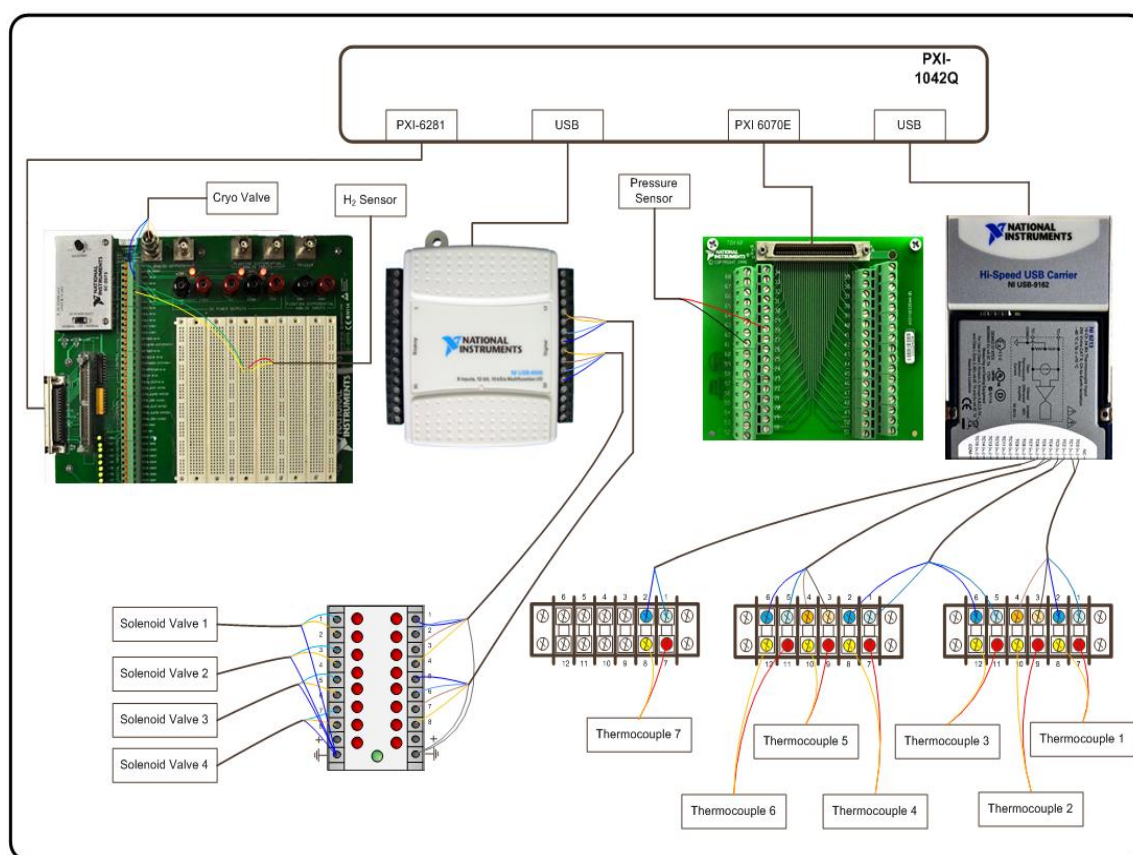


Figure 11. Wiring diagram (Biju Bajracharya).

### Instrumentation

Hydrogen sensor chosen for this task was H2Scan Hy-Optima 700 series hydrogen process monitor. This is based on HCAP and HRES thin film sensor combination and is sensitive to concentrations between 0.5 to 100%. The sensor has a set of internal relays that can be used to control other equipment based on sensor reading. H2Scan is designed to continuously monitor hydrogen levels in static pressure environments with pressure up to 100psi and temperatures down to -20°C. The sensor requires an input voltage of 8 to 13V for proper operation. Output signal is selectable between 4-20mA, 0-10V, 0-5V and 1-5V ([Appendix B](#)). The sensor was initially calibrated for operation in 0.5-4% H<sub>2</sub> concentrations at 1atm pressure.



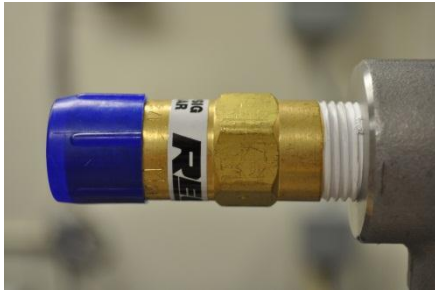
*Figure 12.* H2Scan hydrogen monitor.

Bernard Controls Ball valve was used to physically separate the H2scan sensor from the rest of the setup in case any problems would occur during testing (Figure 13). This valve is controlled by software and can withstand pressures up to 1000psi at  $-200^{\circ}\text{C}$ . Another two manual valves were positioned around the setup to instantly reduce pressure and temperature stress on the hydrogen sensor if any faults are detected during the test procedure (Figure 14).



*Figure 13.* Bernard Controls ball valve. *Figure 14.* Manual pressure release valve.

Other safety equipment consisted of 2 Rego CryoFlow cryogen rated pressure release valves set at 300psi ensured that the liquid nitrogen expanding on the inside of the interior pipe would not be ruptured (Figure 15). Flow safe pressure relief valve was set to 200psi and controlled the pressure inside the main pipe (Figure 16). These safety valves were integral to a safe operation of the test fixture.



*Figure 15.* Rego pressure regulator.



*Figure 16.* Flow-Safe pressure relief valve.

Temperature was recorded using an array of seven thermocouples placed on the inside and outside of the test fixture. Three Omega type K thermocouples were located directly in the gas stream and were attached thru portholes on the test fixture (Figure 17). The remaining four thermocouples were located on the inside of the pipe and used a feed through designed by Conex that was attached directly to the outside to the interior pipe (Figure 18). These sensors were arranged to give a detailed picture of the test stands temperature gradient throughout the testing procedure. These readings helped understand the temperature distribution throughout the fixture. Type K thermocouples can detect temperatures down to  $-200^{\circ}\text{C}$ .



*Figure 17.* Omega K type thermocouple. *Figure 18.* Conax thermocouples.

Pressure sensor chosen for this project was a capacitive pressure transducer designed by Omega. Omega PX1005 is rated down to  $-200^{\circ}\text{C}$  and has a span of 0 to 500psi (Figure 19). This sensor was powered by 10V and used a 24-bit analog input for data acquisition. Pressure reading had to be accurate for accurate measurement of hydrogen content. This sensor was specified to have an accuracy of 0.25%FS or 1.25psi

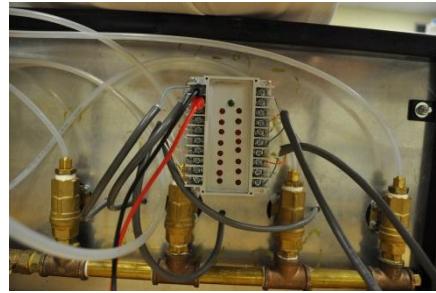


*Figure 19.* Omega PX1005 pressure sensor.

The final design element was a system that comprised of a manifold, 4 ball valves and a valve controller. Four Dyna-Quip ball valves were used to control the flow of gas to the test stand (Figure 20). The valves require 24 1.5A to operate. This power is supplied by a controller that uses solid state relays to open and close the valves based upon the digital input connected to the computer (Figure 21). Gas canisters were used to supply gas to the test fixture.



*Figure 20.* Dyna-Quip ball valves.



*Figure 21.* Custom valve controller.

All the instrumentation is controlled by a computer that uses NI hardware and software to communicate. The following hardware was used to control the test fixture:

- NI PXI-104Q PXI chassis
  - NI USB 6008 – Multifunction I/O (Figure 22).
  - NI TBX-68 – break out board (Figure 23).
  - NI USB-9213 – 16 channel thermocouple data acquisition board (Figure 24).
  - NI SC-2075 – break out board (Figure 25).
  - NI PXI-6070E – Multifunction I/O (Figure 26).
  - NI PXI-6281 – M series Multifunction DAQ (Figure 27).



Figure 22. NI USB-6008 [12].



Figure 23. NI TBX-68 [11].



Figure 24. NI USB-9213 [13].



Figure 25. NI SC-2075 [16].



Figure 26. NI PXI-6070E [9].



Figure 27. NI PXI-6281 [10].

### NI USB-6008

NI USB-6008 is a multifunction Universal Serial Bus (USB) DAQ device. This device was used to control the ball valves that supply the test stand with calibrated gas with specific  $H_2$  concentrations (Figure 22). Device specifications as listed on NI website:

- Eight analog inputs with 12-bit resolution and 10kS/s sample rate (0V - 5V).
- Two analog outputs with 12-bit resolution and 150S/s update rate (-10V - 10V).
- Twelve digital Input Output (I/O) ports (TTL, 8.5mA max).

- 32-bit counter (5Mhz max).
- Power supply port (5V, 200mA).
- USB 2.0 Full-Speed communication port (12Mb/s) [20].

During power on this device sets all digital I/O lines to high impedance. This did not drive the signal high or low, but each line had a pull-up resistor connected to it which delivered a small amount of current anytime the device is plugged in. The manufacturer specified that this part as full speed USB 2.0 but 12Mb/s was a speed for USB 1.1 and USB 2.0 was an effective speed of 480Mb/s. This limited the data sample rate of the device if all ports were used [12].

#### *NI TBX-68 with NI PXI-6281*

NI TBX-68 is a termination block with 68 screw terminals, din rail mounting (Figure 23). This can be used with any 68 pin DAQ device. The termination block was connected to NI PXI-6281, a high accuracy multifunction M series DAQ (Figure 27). These devices were used to acquire data from the H2Scan sensor. This M-series DAQ had the following specifications [10]:

- Sixteen analog single-ended channels or eight differential channels with 18-bit resolution and 625kS/s ( $\pm 10V$ ).
- Two analog outputs with 16-bit resolution and 2.86MS/s update rate ( $\pm 10V$ ).
- 24 digital I/O ports with max clock rate of 10Mhz (TTL, 24mA max).
- Two 32bit counters (80Mhz max).
- PCI eXtensions for Instrumentation (PXI).

PXI port is a combination of Peripheral Component Interconnect (PCI) electrical bus and Eurocard packaging. This combination made the PXI cards more rugged and modular



than its PCI counterparts, but the system price of PXI was much higher than a standard PCI system [10].

#### *NI USB-9213*

NI USB-9213 is a 16 channel USB thermocouple DAQ (Figure 24). This DAQ was used to acquire temperature data from thermocouples placed throughout the test stand without the hassle of building Operational Amplifier (op-amp) circuits for each one of the thermocouples. Datasheet for this device specified [13]:

- Sixteen differential channels with 24-bit resolution and 100S/s sample rate ( $\pm 78.125\text{mV}$ ).
- Differential input impedance of  $78\text{M}\Omega$ .
- Sensitivity of  $0.25^\circ\text{C}$  for K-type thermocouple in high speed mode.
- USB 2.0 Full-Speed communication port.

#### *NI SC-2075 with NI PXI-6070E*

NI SC-2075 is a breakout board with a breadboard (Figure 25) for E series DAQ boards. NI PXI-6070E (Figure 26) used to acquire data from the break out board. Data sheet for this device specified [9][16]:

- Sixteen single ended or eight differential analog inputs with 12-bit resolution and  $1.25\text{MS/s}$  sampling rate ( $\pm 10\text{V}$ ).
- Two analog outputs with 12-bit resolution and  $400\text{kS/s}$  update rate ( $\pm 10\text{V}$ ).
- Eight digital I/O ports (TTL,  $13\text{mA}$  max).
- Two 24-bit counters ( $20\text{Mhz}$ ).

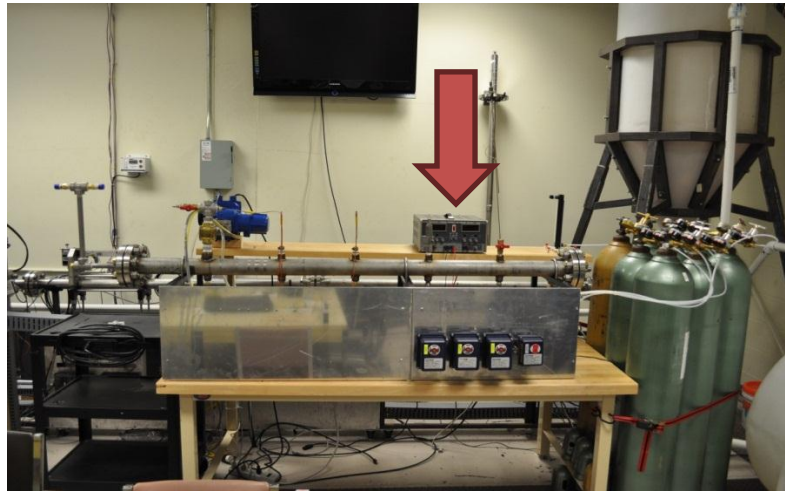


The test stand utilized this DAQ to control the Cryo Valve (Figure 13) and record data from the pressure sensor [9].

### Procedures

Pressure test procedure:

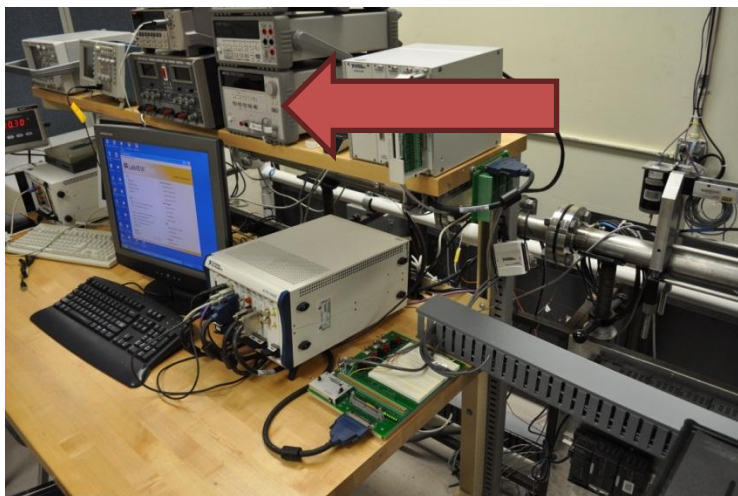
1. Safety goggles have to be worn during all testing procedures.
2. Turn on the NI PXI-1042Q PXI chassis.
3. Open the latest H2 LabVIEW VI.
4. Choose a .txt file that the data will be saved too.
5. Start the VI.
6. Turn on BK Precision 1660 power supply that is connected to the ball valves (Figure 28).



*Figure 28.* BK Precision 1660 power supply.

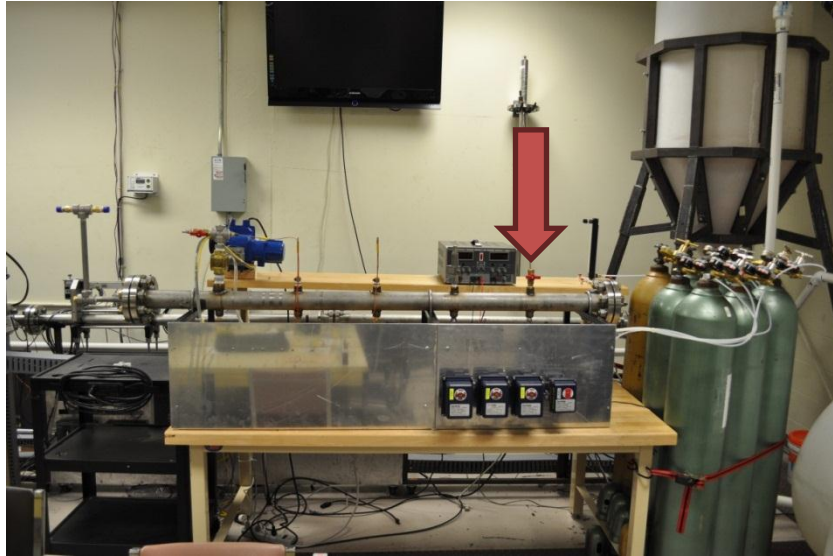
7. Using H2 VI open the first valve that supplies pure nitrogen. (make sure that the nitrogen supply is turned on at the gas cylinder).
8. Perform a full purge of the test stand 5min @ 10psi with nitrogen gas.

9. Turn on the HP E3631A power supply and press recall twice to enable the output and set it to the correct voltage and current limit (Figure 29).



*Figure 29.* HP E3631A power supply.

10. For reference start the H2Scan rs232 communication software to ensure proper operation of the H2Scan sensor.
11. After 5 min the sensor is warmed up and ready to use so all the information will be displayed in the H2 VI.
12. For pressure test close the nitrogen gas and open up the 3%H<sub>2</sub> concentration ramp up the pressure from 0 to 150psi while ensuring the proper concentration is being read by the sensor.
13. If at any point the sensor shows any signs of malfunction turn off the ball valve using the VI then immediately open the red emergency release valve located on the right side of the pipe (Figure 30).



*Figure 30. Red emergency valve.*

14. If the sensor operates normally during the ramp up of the pressure make sure to release the pressure slowly to verify operation on the release of the pressure.

Make sure that all data is recorded to appropriate file if not perform the experiment again.

15. After all pressure tests make sure to release the gases out of the pipe slowly using a bubbler that ensures that the system will not be contaminated with oxygen for further testing.

Temperature testing:

1. Eye and body protection are required for all workers handling cryogenics (Figure 31).
2. Safety goggles are required by everybody that is participating in the experiment.
3. Face shield is required if operating systems under pressure and while connecting and disconnecting lines.



*Figure 31.* Cryo protection gear.

4. Proper footwear is required: open or porous shoes are not permitted in the work area.
5. If the oxygen sensor level reaches a dangerous level of 19.5 (alarm will sound) immediately turn off the ball valve in the VI then the liquid nitrogen valve and evacuate the area.
6. Turn on the NI PXI-1042Q PXI chassis.
7. Open the latest H2 LabVIEW VI.
8. Choose a .txt file that the data will be saved too.
9. Start the VI.
10. Turn on BK Precision 1660 power supply that is connected to the ball valves (Figure 28).

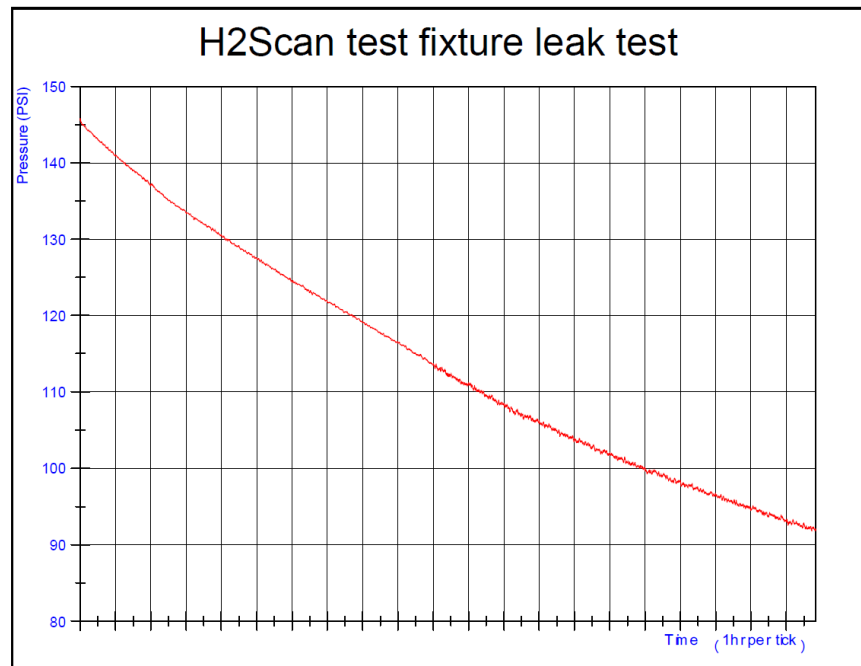
11. Using H2 VI open the first valve that supplies pure nitrogen (make sure that the nitrogen supply is turned on at the gas cylinder).
12. If the stand was not previously purged perform a full purge of the test stand 5min @ 10psi with nitrogen gas.
13. Turn on the HP E3631A power supply and press recall twice to enable the output and set it to the correct voltage and current limit (Figure 29).
14. For reference start the H2Scan rs232 communication software to ensure proper operation of the H2Scan sensor.
15. After 5 min the sensor is warmed up and ready to use so all the information will be displayed in the H2 VI.
16. Turn on the liquid nitrogen supply till the inside pipe is full of liquid nitrogen (some liquid nitrogen will come out of manual ball valve on top of the fixture).
17. When the minimum temperature of  $-20^{\circ}\text{C}$  is reached open up the pressure release valve located on right side of the fixture.
18. If the sensor shows any signs of malfunction turn of the ball valve supplying the gas stream and open the pressure release valve located on the right side of the fixture (Figure 30).
19. At the end of the test procedure evacuate all the remaining gas through a bubbler to ensure no oxygen gets in the system during the gas evacuation.

## CHAPTER IV

### EXPERIMENTAL RESULTS

#### System Calibration

Calibration was an important step that ensured that every device in the test stand had an output that is repeatable and accurate. The first step to calibration of all the sensors was to ensure that the test stand was properly sealed and had no leaks. A pressure leak test was conducted over 42 hours to ensure system leaks are minimal (Figure 32).



*Figure 32.* Test fixture leak test.

The pressure leak test showed average leak rate of 1.08psi per hour. Testing would happen over maximum period of two hours so the leak rate was deemed acceptable for testing of the H2Scan sensor.

Pressure transducer was calibrated using a pressure gauge. The pressure was ramped up in 15 psi increments and the output of the sensor was recorded at every step (Table 1).

The pressure sensor gives a differential reading so zero psi sensor reading would be equal to around 14.7 psi absolute pressure.

Table 1

*Omega PX1005 Calibration Data*

Input Pressure (PSI)	Output signal ( $\Omega$ )
0	13
15	23
30	34
45	43
60	53
75	64
90	75
105	87
120	97
135	108
150	117

The calibration data was then entered into LabVIEW software for the program to convert the raw data (ohms) to the pressure inside the pipe. The PX1005 has accuracy of 0.25%FS this means that error can be as much as  $\pm 1.25$ psi. Pressure sensor reading can introduce an error of  $\pm 0.085\% \text{H}_2$  to the final reading from the hydrogen sensor.

H2Scan sensor had to be calibrated using certified calibrated gasses to achieve the manufacturer specified accuracy. To conserve gas during the calibration procedure a separate manifold was designed using half inch steel tubing (Figure 33). Certified calibrated gases were acquired from Nordan Smith a local specialty gas supplier. The rs232 connection procedure is outlined in the sensors application note (Appendix A) was used to create a serial communication interface (Figure 34).

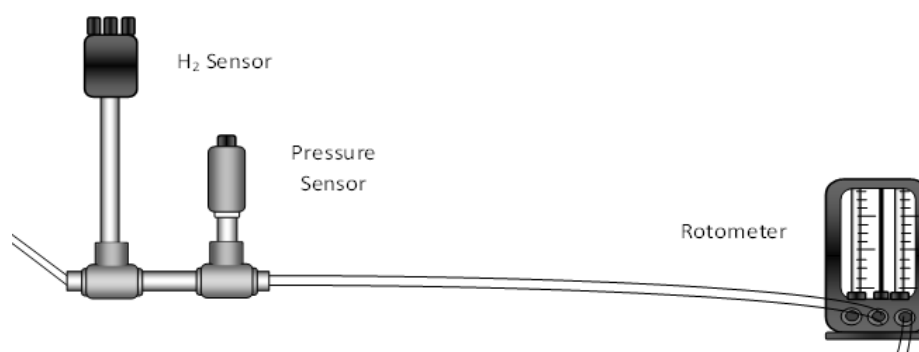


Figure 33. Manifold for H2Scan calibration.

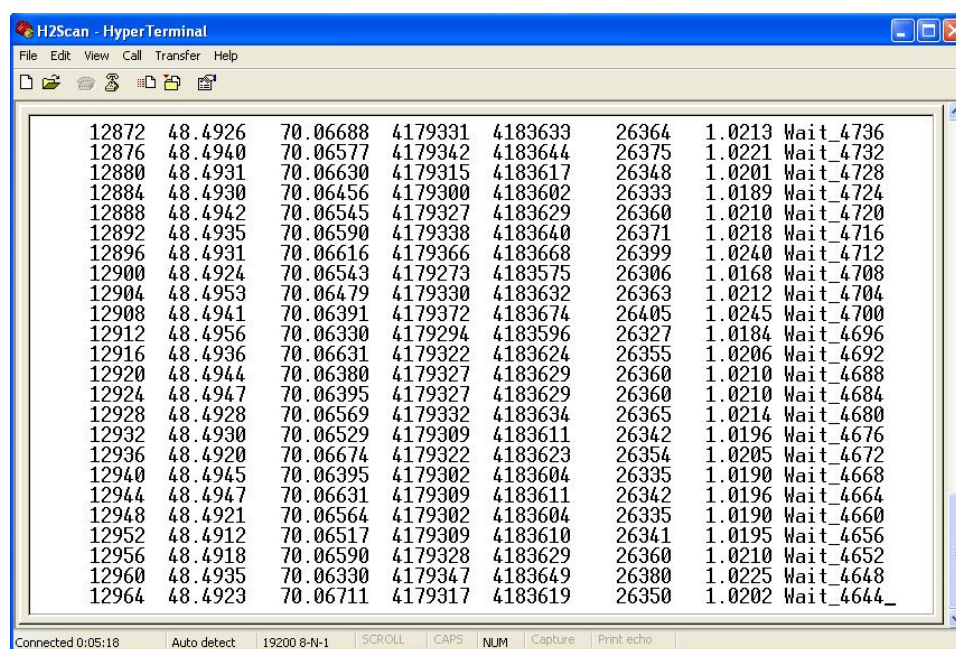


Figure 34. H2Scan serial interface.



The calibration procedure performed on the hydrogen sensor followed the manufacturer's manual (Appendix B). Results of calibration and field verification procedures were within manufacturer's tolerance specifications (Equation 2) (Figure 35).

$$\text{Tolerance} = \pm(0.03 \times \text{indication} + 0.2) \% \text{ hydrogen by volume}$$

---

Equation 2: Tolerance calculation (Appendix B).

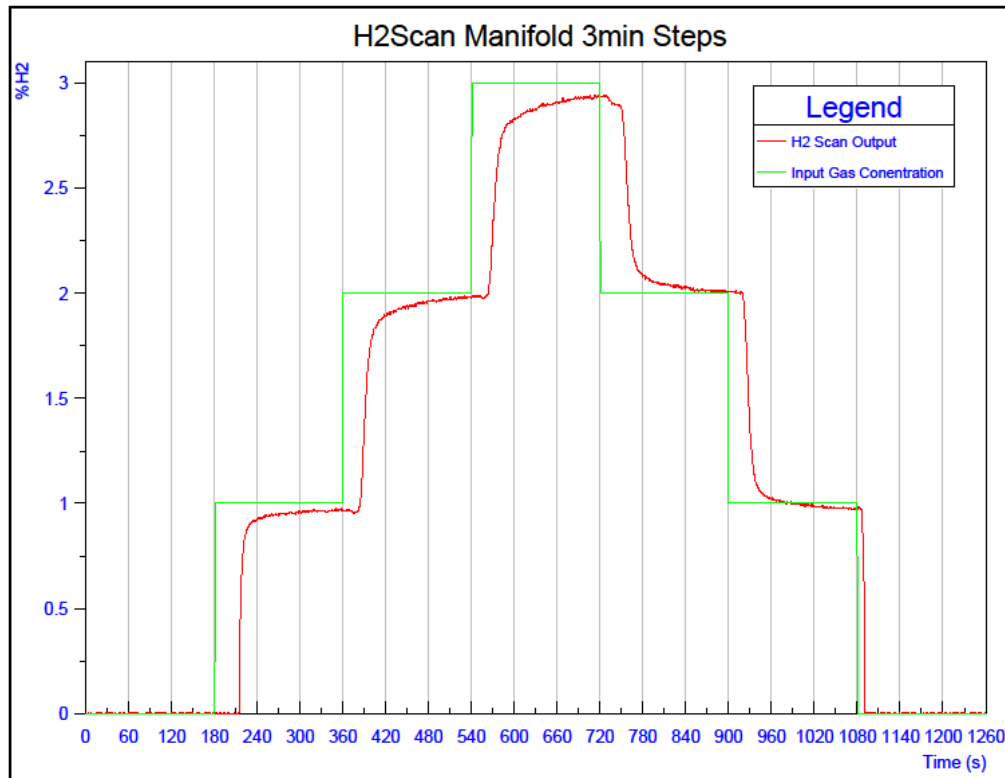


Figure 35. Calibration verification data.

Maximum error during verification procedure was -0.23% with input gas at 3% allows for  $\pm 0.3131\%$  tolerance so the sensor was considered calibrated and in tolerance.

Purchased sensor is sensitive to hydrogen levels of 0.5%-4% so the response to 0%-1% change in gas concentration was not gradual (Appendix B).

DynoQuip vall valves that control the flow of input gas were controlled by a solid state controller was designed and built in house. This controller was designed using Solid State Relay's (SSR). SSR is a solid state electronic device that uses a small current to control the flow of a much larger current. Controller accepts Transistor-Transistor Logic (TTL) input of 15mA from the NI USB-6008 digital outputs and controls the 24 volt 1.5A signal to the ball valves (Figure 36). The USB DAQ was not able to provide enough current to turn on the SSR, so pull up resistors where connected to the +5V port to provide the required current of 20mA.

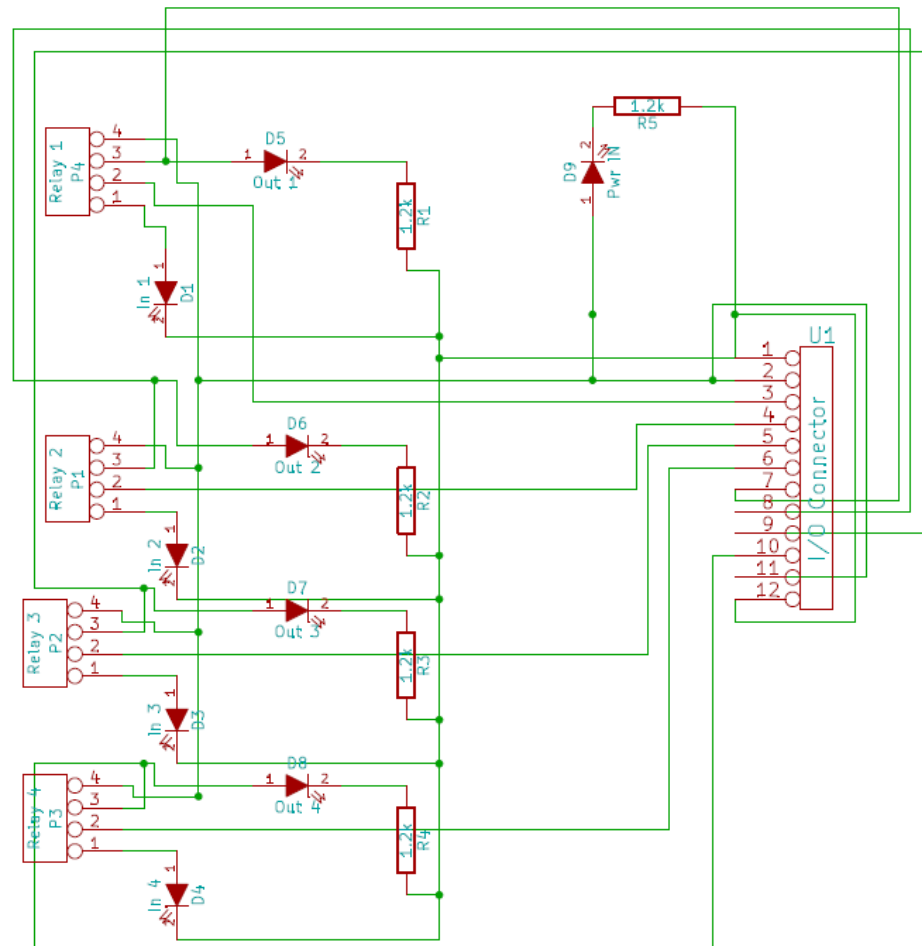


Figure 36. Valve controller schematic (Roger Harrison).

This design then was printed on a circuit board in house by Roger Harrison who is one of our undergraduate students in the electronics engineering technology program. The CAD layout of the finished board is shown in Figure 32.

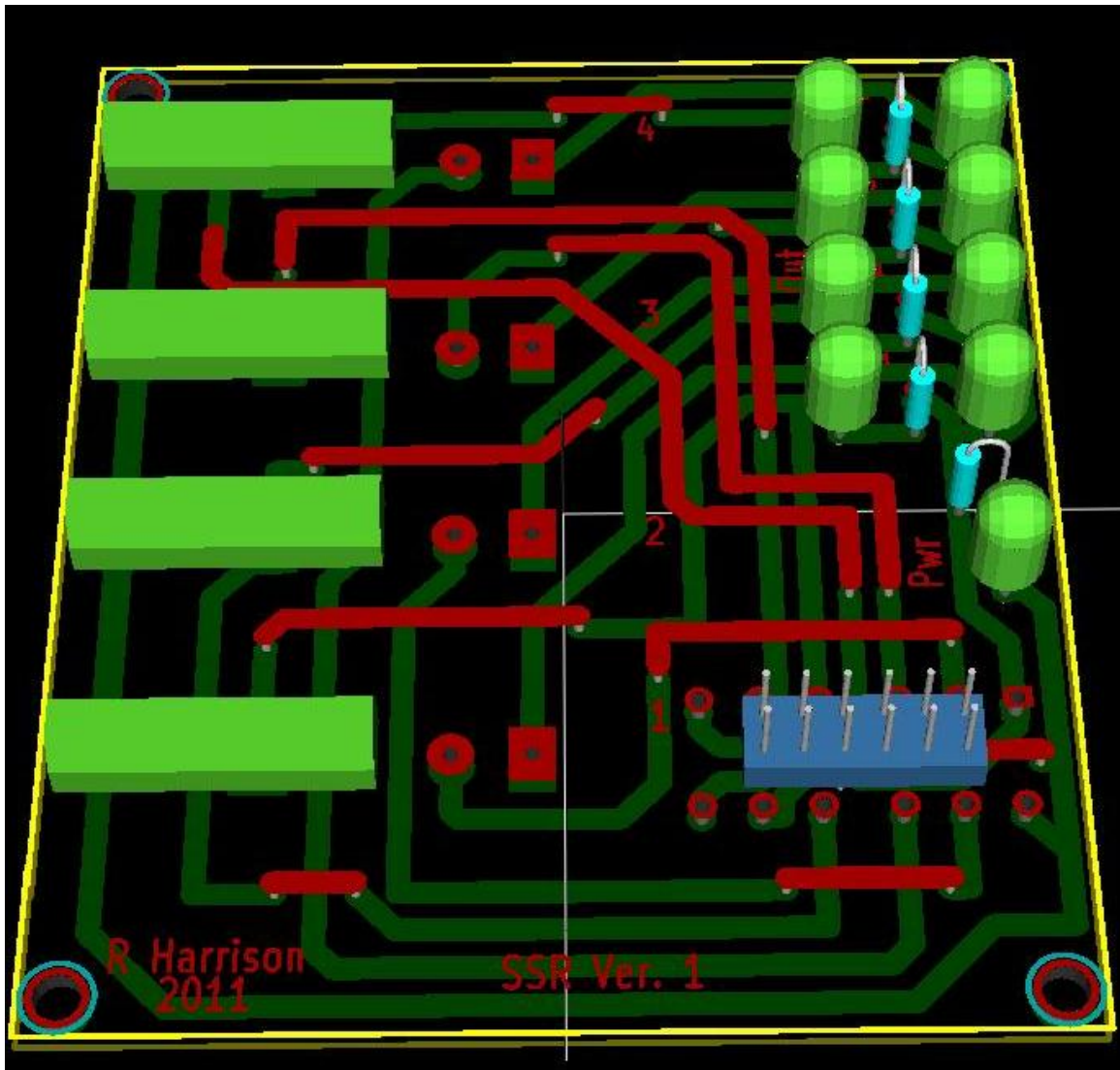


Figure 37. Valve controller CAD layout.

#### Test Fixture Software

Software for the test fixture was written using LabVIEW programming language.

The program was designed to simultaneously acquire data from ten sensors while

controlling six outputs to all the instrumentation on the test fixture. The timer inside the program was used to create predefined test with and without human interference. All the data that was entered and acquired was saved into a tab delaminated text file for further analysis and records. The final LabVIEW virtual instrumentation front panel was designed for easy readout of all the sensors and also functioned as the input panel for all the peripheral on the test stand.

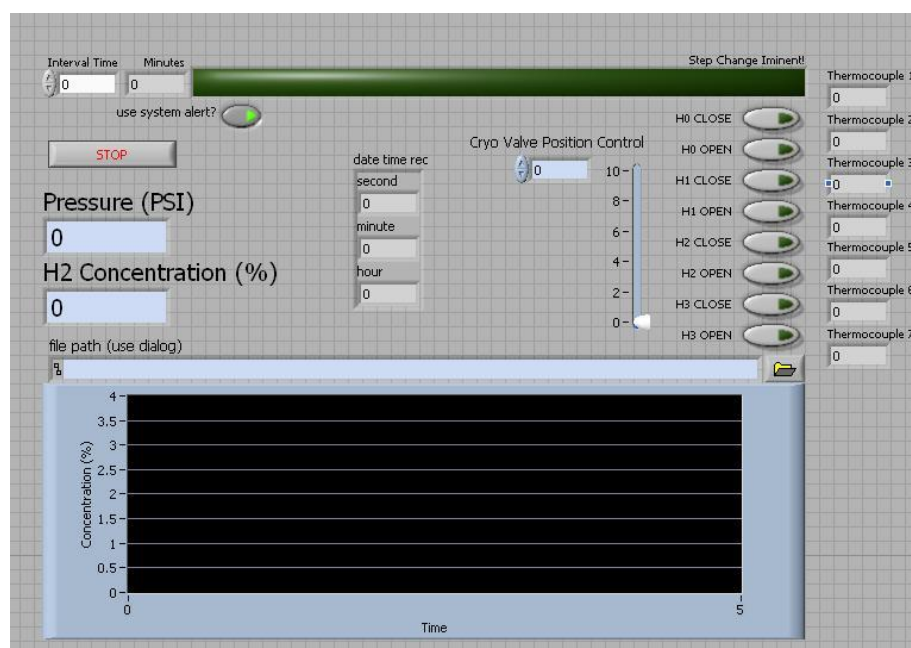


Figure 38. VI front panel.

File path would have to be entered before the initialization of the program so Random Access Memory (RAM) was not used during the test at all. By minimizing the RAM use during program execution the computer was responsive to all the user inputs. Timer could be set up to either remind the user of an upcoming change or perform that function autonomously using the outputs built into the program. Block diagram for the program showed the timings used to acquire data and the overall data flow inside the program (Figure 39).

h2vi.vi

C:\Documents and Settings\PXI1042Q\Desktop\STTR 1 H2 program\h2vi.vi

Last modified on 6/7/2011 at 2:37 PM

Printed on 6/10/2011 at 7:13 AM

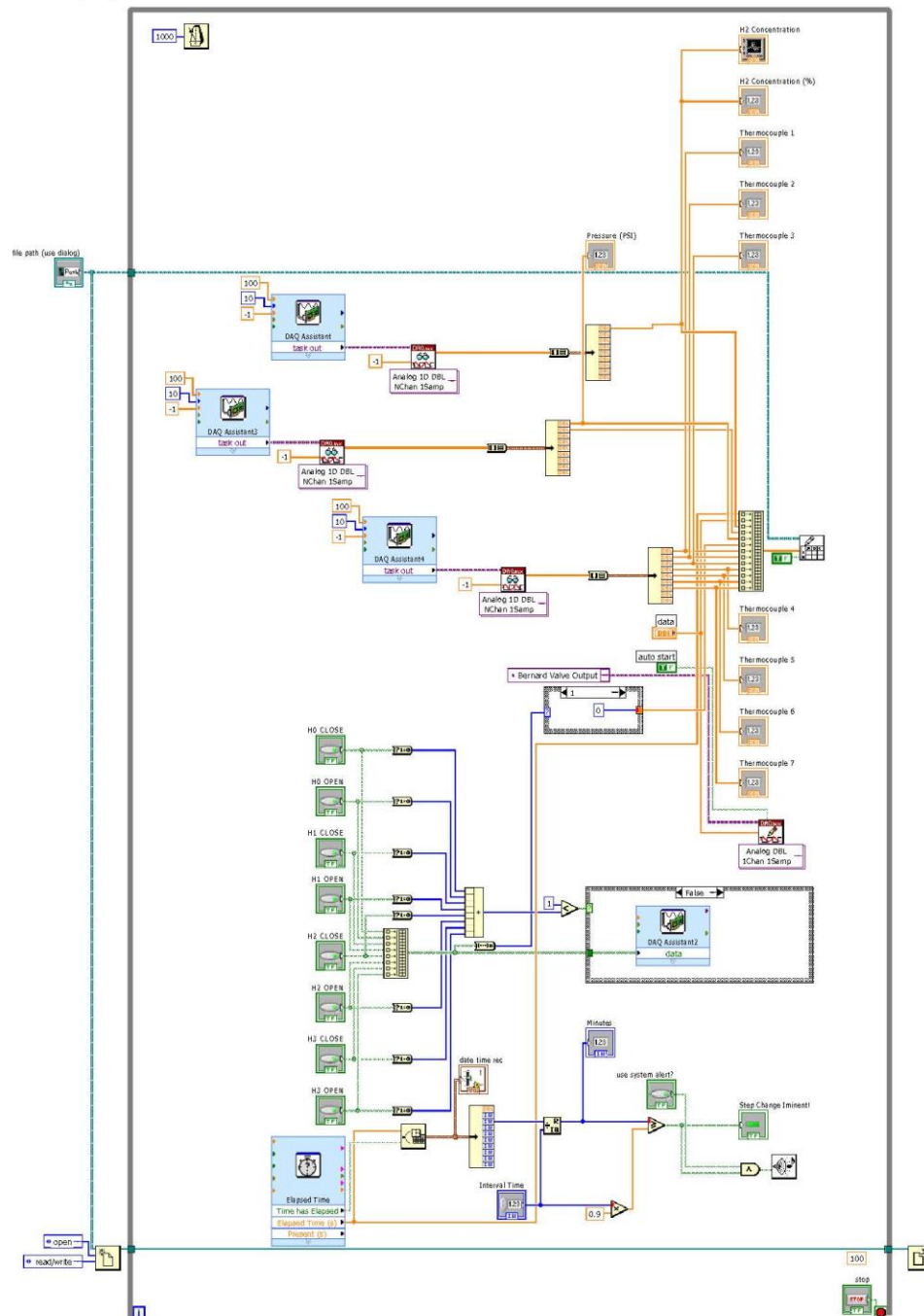


Figure 39. LabVIEW block diagram.

### Data Analysis

Several tests were conducted to ensure that the sensor is capable of operating within the manufacturer specifications. HY-Optima H<sub>2</sub> sensor specifications showed pressures up to 100psi at temperatures as low as -20°C were recommended stopping points for the tests (Appendix B). Tests were broken down into pressure and temperature test to simplify the data analysis.

Pressure test was conducted using the procedure outlined in the previous chapter to ensure proper operation of the sensor all the way up too 100psi. Due to H2Scans sensitivity to pressure the sensor output had to be correlated to internal pressure of the pipe. The following formula was used to acquire the proper readout from H2Scan sensor:

$$H_2(\%) = \frac{H2Scan\ input}{1 + (Pressure(psi) * 0.0680459639)}$$

---

Equation 3: H2Scan pressure offset formula (Appendix B).

The effect of this relationship can be seen in Figure 27. Final version of the software was able to calculate the adjusted hydrogen concentration in real-time. The program was taking and averaging 1000 samples of pressure readings and hydrogen reading every second then using equation 2 to find the actual hydrogen concentration. Sensors output remained within the acceptable range throughout the pressure tests (Figure 40). Due to ideal gas law the standoff did not provide any protection from high pressure so standoff designs were not analyzed during pressure tests.

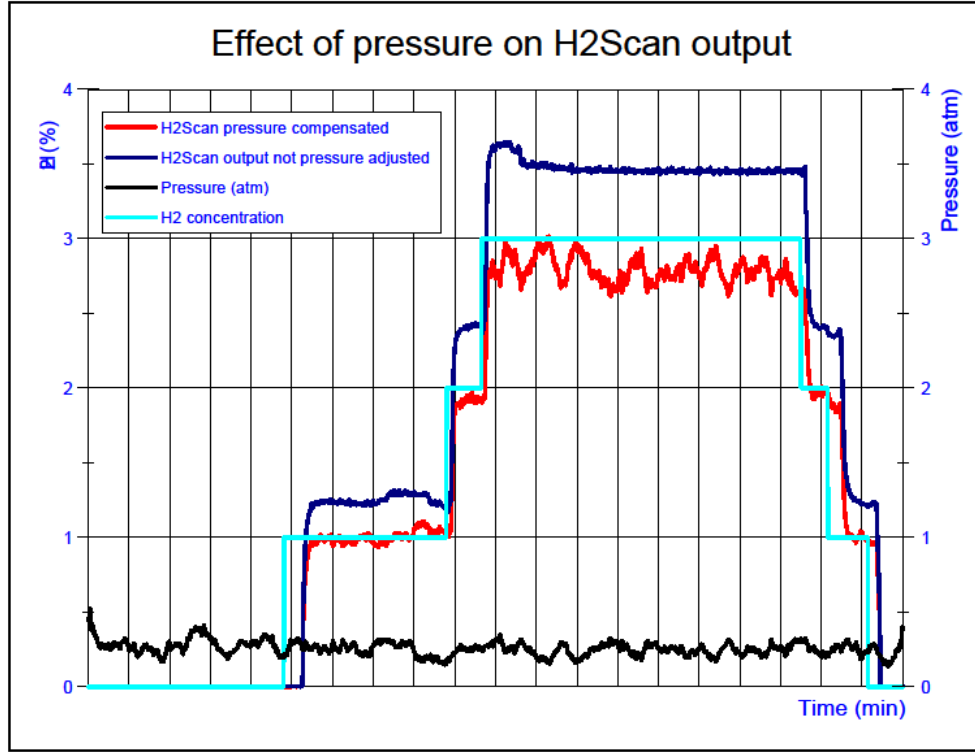


Figure 40. Effects of pressure on H2Scan output using 12-bit DAQ.

Figure 40 was analyzed and showed excessive ripple during 3% concentration. The ripple comes from pressure sensor noise displayed in black. It was concluded that DAQ sensitivity of 12-bits was not enough to read an input of 0-30mV. Resolution of 12-bits would equal to maximum resolution of 2.44mV which would equal to  $\pm 4.066$  psi (Equation 4). Error of  $\pm 4.066$ psi is not acceptable for this test as it would introduce a hydrogen concentration error of 0.276% at 1%.

$$V_{in} = \frac{1V}{2^{12}} = 0.244mV$$

$$Resolution(psi) = \frac{0.244mV * 500psi}{30mV} = 4.066psi$$

---

Equation 4: Resolution of pressure sensor using 12-bit input.

Pressure sensor was switched to an input with a resolution of 24-bits which equals to maximum input resolution of 0.5967nV (Equation 5).

$$V_{in} = \frac{1V}{2^{24}} = 0.596nV$$

$$Resolution(psi) = \frac{0.596nV * 500psi}{30mV} = 0.033psi$$

---

Equation 5: Resolution of pressure sensor using 24-bit input.

Maximum error of 0.033psi was calculated as acceptable. After this adjustment a secondary pressure test was conducted using the proper procedure. The results of secondary test are displayed in Figure 41.

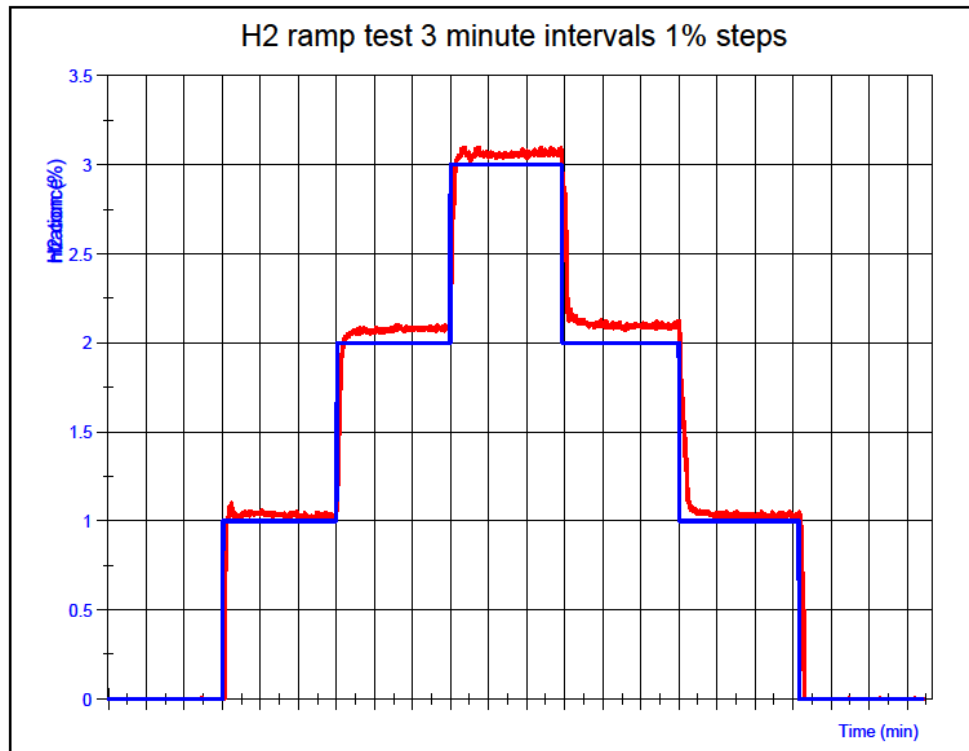


Figure 41. H2Scan pressure ramp test using 24-bit DAQ.



The test was successful the sensor was able to operate at 100psi pressure without producing the ripple effect described previously. The final test was performed at a constant pressure and error was within the manufacturer specifications.

To verify proper operation in low temperatures a test was conducted using the temperature testing procedure outlined in the previous chapter. The sensor did not exhibit any problems operating at  $-20^{\circ}\text{C}$  (Figure 42). Temperature experience by an object that is eight inches away from the source will be increased on average from  $-100^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$  [8].

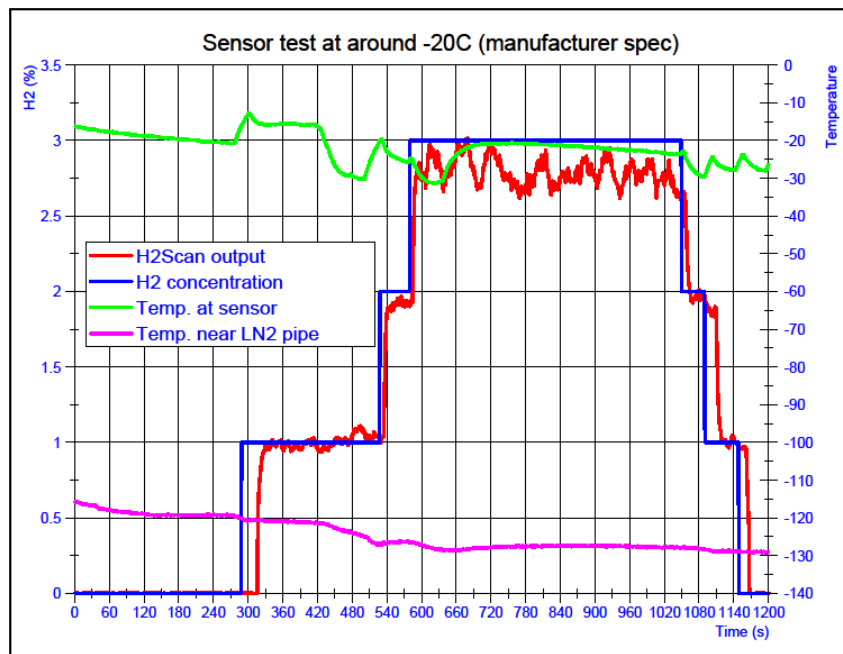


Figure 42. H2Scan test at  $-20^{\circ}\text{C}$ .

All the error was that is visible in Figure 42 was introduced by the pressure sensor input noise described previously and was ignored. Temperature inside the test fixture reached a minimum of  $-130^{\circ}\text{C}$  where a sensor mounted 8 inches of the pipe reached a minimum temperature of  $-30^{\circ}\text{C}$ .

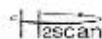
## CHAPTER V

### CONCLUSION

The test stand has produced the required conditions to test the operational thresholds for H2Scan sensor. The standoff of eight inches as initially configured was enough to change the temperature of the gas coming from the fixture without a bypass or other configuration options. The test stand dipped in temperature all the way down to over negative hundred and thirty degrees Celsius. This initial configuration was not capable of decreasing the temperature beyond the sensor potential. Further enhancements to the setup like insulation will increase the efficiency of the setup without adding substantial additional cost. Pressure sensor provided accurate enough data to compensate for pressure fluctuations without introducing any noise to the final hydrogen concentration data. A set up that includes with isolation valve, pressure transducer, thermocouple and H2Scan sensor was deemed to be sufficient to successfully automate the rocket engine test stand. If correctly implemented this equipment is capable of reducing the cost of testing liquid rocket engines for NASA and saving the dwindling helium reserves for future generations.

## APPENDIX A

## H2SCAN APPLICATION NOTE



## APPLICATION NOTE

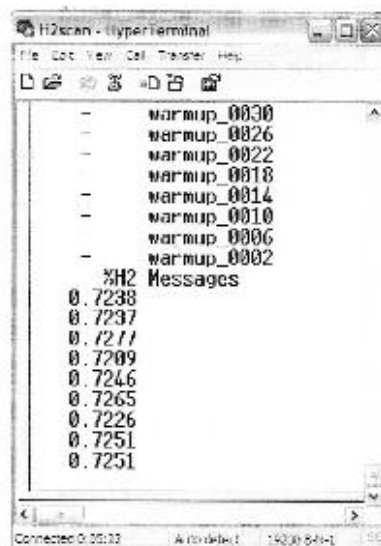
Using Hyper Terminal with H2scan Models 600/700

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 Released Date: **27 Dec 06** Page: **2 of 2**

4) After accepting the "Connect To" choice you will be queried for the "Com Properties". Choose the options as shown below:



5) After accepting the "Com Properties" Hyper Terminal will display the data window. An example showing the H2Scan transitioning from warm-up to normal operation is shown below.



COMPANY CONFIDENTIAL  
 THE INFORMATION CONTAINED HEREIN IS PROPRIETARY TO H2SCAN  
 AND MAY BE REPRODUCED, REPRODUCED, OR DISCLOSED TO ANY OTHER PARTY WITHOUT PERMISSION FROM H2SCAN.

## APPENDIX B

## H2SCAN MANUAL

**HY-OPTIMA™**

HYDROGEN SPECIFIC MEASUREMENT SOLUTIONS

**HY-OPTIMA™ 700 Process Hydrogen Analyzer****OPERATING MANUAL**

28486 Westinghouse Place, Suite 100  
Valencia, California 91355, U.S.A.  
Tel: (661) 775-9575 / Fax: (661) 775-9515  
E-mail: [sales@h2scan.com](mailto:sales@h2scan.com)  
Website: <http://www.h2scan.com>



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**WARNING: H2SCAN'S HY-OPTIMA™ 700 PROCESS HYDROGEN ANALYZERS ARE CALIBRATED IN A HYDROGEN/NITROGEN (H<sub>2</sub>/N<sub>2</sub>) BACKGROUND AND SHOULD NEVER BE OPERATED IN AN AIR OR OXYGEN BACKGROUND.**

After warm-up, the HY-OPTIMA™ 700 Analyzer should be run in a hydrogen concentration exceeding 5% by volume for at least an hour. Oxygen will readily adsorb on the HY-OPTIMA™ 700 Analyzer and can confound the hydrogen measurements. If the sensors are left in oxygen, air or any environment without hydrogen for long periods of time, they must be conditioned in hydrogen to remove adsorbed oxygen and taken through the Verification process to check accuracy. Failure of the Verification will require that the sensors go through Calibration. Both procedures are described later in this manual.

The HY-OPTIMA™ 700 Analyzer can be exposed to oxygen for short periods of time without adverse effects if the unit is turned off. If the units are operated in oxygen or stored in air for longer than a week, the units' hydrogen readings may be high due to oxygen adsorption on the sensor. Hydrogen exposure will then cause the readings to drift lower as adsorbed oxygen is slowly removed and the unit recovers to normal steady behavior.

If this drift behavior is observed, the sensor should be conditioned by operating in a hydrogen concentration exceeding 5% until the readings are stable. The required hydrogen conditioning may vary from several hours to several days depending on the level of oxygen exposure. Higher hydrogen concentrations used during conditioning may accelerate the process. Once stable, the unit should be taken through Verification to check accuracy and Calibration if needed.

Step	Description
1	Power units on in 5% H <sub>2</sub> /N <sub>2</sub> by volume or greater
2	Operate the HY-OPTIMA™ 700 Analyzer in the 5% H <sub>2</sub> /N <sub>2</sub> or greater gas for six hours or longer
3	Check to see if the sensor readings were accurate and stable over that time
4	If the readings are not accurate and stable, condition the sensor in 5% H <sub>2</sub> /N <sub>2</sub> or greater gas overnight and perform the Verification and Calibration described later in this manual



## 2.5 Settings

The unit's operational and output settings have been configured at the manufacturer with settings specified at the time of purchase. Settings may be changed through the use of Serial Communication as described in section 3, or through the use of an Optional User Interface Module.

**WARNING: IF SETTINGS ARE CHANGED FROM THOSE SET BY THE MANUFACTURER THEN IT IS THE USER'S RESPONSIBILITY TO UNDERSTAND THE IMPLICATIONS TO THE CONNECTING EQUIPMENT MONITORING THE UNIT.**

## 2.6 Visual Status Indicator

Located on the front of the unit next to model number marking, the Status Indicator LED displays basic unit function as described below.

Status	Indicator Color
Normal operation / Hydrogen Detected below R1 set point	GREEN
Warm-up / Hydrogen Detected above R1 and below R2 set points	AMBER
Hydrogen Detected above R2 set point/ Unit fault detected	RED

## 2.7 Optimum Unit Performance

For maximizing the performance of the sensor, the following steps are recommended.

- Verify that all electrical connections are made as recommended. Switching the polarity can cause damage to the unit. Ensure that the DC power supply utilized is appropriate and does not have large peak-to-peak noise.
- Perform a Field Calibration after installation and conditioning steps described in the Start-up section are completed.
- If the unit gets exposed to extended periods of no H<sub>2</sub> (or some Oxygen), condition the sensor as described in the Start-up section and follow-up with a Field Verification (and Field Calibration, if needed).
- Effect of pressure: The HY-OPTIMA™ 700 Analyzer is hydrogen specific and sensitive to only the hydrogen partial pressure in the gas stream. Since changes in total gas pressure will affect the hydrogen partial pressure, they will also affect the sensor readings. For instance, at one atmosphere pressure, a 50% H<sub>2</sub>/N<sub>2</sub> mixture will be reported as 50% from the unit. At 1.1 atm, the reading will increase to 55% and two atms will result in a reading of 100%. In fact, the HY-OPTIMA™ 700 Analyzer are capable of measuring multiple atmospheres of hydrogen and readings above 100% H<sub>2</sub> are interpreted as hydrogen pressures above one atmosphere. So, for example, a reading of 150% H<sub>2</sub> means 1.5 times the hydrogen pressure of a 100% H<sub>2</sub> concentration at one atmosphere. At the factory, the units are calibrated at one atmosphere pressure. Performing the Field Calibration at the operating pressure will display the pressure corrected reading. For example, if the local atmospheric pressure is 0.97 atm, doing a Field Calibration will correct for this.





- Verification/Calibration gas bottle accuracy: The inaccuracy of the gas bottle concentration will directly affect the measured accuracy by the units. During factory calibration, the units are calibrated with high accuracy gases (as high as +/- 0.02% accurate). It is strongly recommended that the user perform calibration with similar high accuracy gases to maintain the accuracy specified in the manual.

### 3.0 Electrical & Communication

**WARNING: IF THE UNIT IS INSTALLED IN A CLASSIFIED LOCATION THEN IT IS THE RESPONSIBILITY OF THE USER AND INSTALLER TO MAKE CONNECTIONS TO RELATED EQUIPMENT IN A MANNER CONSISTENT WITH THE LOCATION CLASSIFICATION.**

#### 3.1 Connections

##### **Power/Analog Output - Connector 1**

Supplied Cable – 4m (12 ft.) standard length (Other lengths available)

Wire Color	Description
Brown	+8 VDC to +13 VDC
White	VDC Return
Black	Positive Analog Output
Blue	Analog Output Return

##### **Relays (Optional) - Connector 2**

Supplied Cable – 4m (12 ft.) standard length (Other lengths available).

Wire Color	Description
Grey	Relay 1 Common
Pink	Relay 1 Normally Closed (NC)
Black	Relay 1 Normally Open (NO)
White	Relay 2 Common
Blue	Relay 2 Normally Closed (NC)
Brown	Relay 2 Normally Open (NO)

##### **Serial Interface (Optional) / Remote User Interface Module (Optional) - Connector 3**

Supplied Cable – 4m (12 ft.) standard length (Other lengths available).

Wire Color	RS232 (standard)			RS422 (optional)		
	Description	DB9 Pin	DB25 Pin	Description	DB9 Pin	DB25 Pin
Brown	+6V (N.C.)					
White	TxD (Device Transmit)	3	2	TxD- (Device Transmit, Negative)	3	2
Blue	-	-	-	TxD+ (Device Transmit, Positive)	4	3
Black	RxD (Device Receive)	2	3	RxD- (Device Receive, Negative)	2	20
Grey	-	-	-	RxD+ (Device Receive, Positive)	6	8
Pink	Ground	5	7	Ground	5	7





### 3.2 Analog Output

The user can request for a specific output current or voltage range or there are a number of standard analog output ranges the user can select from, which are listed below. The analog output the user selects is scaled to the user's hydrogen range of interest. All of this is initially set at the factory per customer specification at the time of order.

Below is the table for standard analog output current ranges:

Current Analog Output Range	Power-On Self Diagnostic	Error
4 mA to 20 mA	2 mA	3 mA
0 mA to 20 mA	0 mA	20 mA

The user can change to another current range of the analog output in the field. Please refer to the "I" command in *Section 4.3 SERIAL COMMUNICATION*.

Below is the table for standard analog output voltage ranges:

Voltage Analog Output Range	Power-On Self Diagnostic	Error
0 V to 5 V	0 V	5 V
1 V to 5 V	0.5 V	0 V
0 V to 4 V	5 V	4.5 V
0.5 V to 4.5 V	0 V	5 V

The user can change to another voltage range of the analog output in the field. Please refer to the "V" command in *Section 4.3 SERIAL COMMUNICATION*.

**WARNING: THE USER CANNOT CHANGE FROM A CURRENT RANGE TO A VOLTAGE RANGE OR FROM A VOLTAGE RANGE TO A CURRENT RANGE OUT IN THE FIELD. THIS REQUIRES A FACTORY MODIFICATION.**



### 3.3 Serial Communication

The user can monitor output and interface with the unit to perform calibration or adjust user settings via the serial communication connector. The serial communication is accomplished via an RS232 (optional RS422) interface.

**Serial Communications Software** - Any serial port two-way communications software such as terminal emulators (HyperTerminal, Telnet, etc.) and purpose-built software (using LabView, Visual Basic, C++, etc.) can be used to establish serial communication with the unit.

#### Format and Settings – RS232 (RS422 optional)

- 19200 Baud
- 8 bit data
- 1 stop bit
- No parity
- Xon/Xoff

**Data Display** – Streaming data is presented in column format. Once serial communication is established and the unit is operating in normal mode, data will be displayed in the user specified format. The display output options are configured via a serial command as described in the following sections (refer to the *SERIAL COMMUNICATION COMMANDS*, *FORMAT <fmt>*, and *OPTIONS <opt>* sections). Columnated data available are as follows:

#### <fmt> Format (these appear in their own columns)

- Timestamp (an integer count at 0.25 sec intervals)
- Printed Circuit Board (PCB) Temperature in °C
- Sensor Temperature in °C
- Raw Analog Data Converter (ADC) Values
- Calibrated Hydrogen Values
- Peak Hydrogen Values

#### <opt> Options (these status data appear in the MESSAGES column)

- Calculation Errors
- Heater State

What follows are examples of typical user specified outputs:

#### Example 1:

Sample serial data with column headers – Calibrated H2% and Messages only

Display	User Response
H2scan:	Type "g 02 06"

%H2	Messages
0.0000	
0.0000	
0.0000	

**Example 2:**

Sample serial data with column headers– Multiple Outputs Specified

Display	User Response
H2scan:	Type "g b2 06"

Time stamp	Pcb Temp	Snsr Temp	%H2	Messages
264	28.8530	124.50800	0.0000	
280	29.1979	124.50910	0.0000	
296	29.5169	124.51110	0.0000	
312	29.7951	124.51320	0.0000	

**Serial Communication Commands** – The unit can be communicated with and configured via the use of commands as described below. Two levels of communication outputs are available:

- Level 0 – Default level used for data monitoring and basic functions providing a continuous stream of data readings
- Level 1 – Password protected level used for configuration of user-settable parameters; interactive single-line data output per command

**Command Summary** – The **RETURN** or **ENTER** key is the last character of the command string. If either key is pressed without a command string the result is an invalid command and will resume continuous display if in Level 0 or return to prompt if in Level 1.

Level 0 Commands	
Keystroke	Description
ESC	Stops continuous display to enter a password or command. If in level zero, the continuous display will resume after executing one command.
sp(spacebar)	Pressing the Space key while the serial output is active will display a label line showing the heading for each column of data.
A	Average readings.
C	Clear peak hydrogen value.
=<password>	Enter the password to change security level. A null or invalid password returns to the default security level. Level 0 password = "0" Level 1 password = "h2scan"



**Format <fmt>** - The Format <fmt> string is a two character hexadecimal representation of an 8 bit value derived from the following table. The user determines which data is needed and selects that bit value. Once all selections are made the values are summed bitwise and then converted to a two place hexadecimal value. To aid in the conversion, a 4 bit to hexadecimal conversion table follows in *EXAMPLE 3*.

Format: Bit Value Identifiers								
Serial output Format <fmt> parameter: select the desired columns of data from this list, add the bit value for each column bitwise, and convert into two hexadecimal characters using the 4 bit-to-Hexadecimal table in <i>EXAMPLE 3</i> .								
Description	Bit Value							
Include time stamp	1	0	0	0	0	0	0	0
Include raw ADC values	0	1	0	0	0	0	0	0
Include PCB temperature	0	0	1	0	0	0	0	0
Include sensor temperature	0	0	0	1	0	0	0	0
Include capacitor reading	0	0	0	0	1	0	0	0
Include resistor reading	0	0	0	0	0	1	0	0
Include overall hydrogen reading	0	0	0	0	0	0	1	0
Include peak hydrogen reading	0	0	0	0	0	0	0	1

**Options <opt>** - The Options <opt> string is a two character hexadecimal representation of an 8 bit value derived from the following table. The user determines which data is needed and selects that bit value. Once all selections are made the values are summed bitwise and then converted to a two place hexadecimal value. To aid in the conversion, a 4 bit-to-Hexadecimal conversion table follows in *EXAMPLE 3*.

Options: Bit Value Identifiers								
Serial output Options <opt> parameter: select the desired status messages from this list which will appear in the MESSAGES column, add the bit value for each column bitwise, and convert into two hexadecimal characters using the 4 bit-to-Hexadecimal table in <i>EXAMPLE 3</i> .								
Description	Bit Value							
Calculation Errors	0	0	0	0	0	1	0	0
Heater State	0	0	0	0	0	0	1	0

**Example 3:**

The user wishes to implement the "G" command ("Go" command, refer to *LEVEL 1 COMMANDS* table) to have the following serial output columns reported from the monitor: Time Stamp, Capacitor Reading, Overall Hydrogen Reading, the Peak Hydrogen Reading, Calculation Errors, and the Heater state.

From the *FORMAT <fmt>* table above, you identify your desired columns with its corresponding bit value:

<u>&lt;fmt&gt; Descriptions</u>	<u>&lt;fmt&gt; Bit Value</u>
Time Stamp	1000 0000
Capacitor Reading	0000 1000
Overall Hydrogen Reading	0000 0010
Peak Hydrogen Reading	0000 0001

<fmt> 4 Bit Value Combination: **1000 1011**

4 bit value	Hexadecimal Character
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

Now use the 4 *BIT-TO-HEXADECIMAL* table above to convert this 4 bit value combination into a two place hexadecimal value:

**<fmt> Two Place Hexadecimal Value: 8b**

From the *OPTIONS <opt>* table above, you identify your desired columns with its corresponding bit value:

<u>&lt;opt&gt; Descriptions</u>	<u>&lt;opt&gt; Bit Value</u>
Calculations Errors	0000 0100
Heater State	0000 0010

<opt> 4 Bit Value Combination: **0000 0110**

Again, use the 4 *BIT-TO-HEXADECIMAL* table to convert this 4 bit value combination into a two place hexadecimal value:

**<opt> Two Place Hexadecimal Value: 06**

**Conclusion:** To have the Time Stamp, Capacitor Reading, Overall Hydrogen Reading, the Peak Hydrogen Reading, Calculations Errors and Heater State columns continuously reported, you will implement the "G" serial command ("Go" Command, refer to *LEVEL 1 COMMANDS* table) as follows at the **H2scan**:  
 command prompt: **G <fmt> <opt> = g 8b 06**

Display	User Response
H2scan:	Type "g 8b 06"



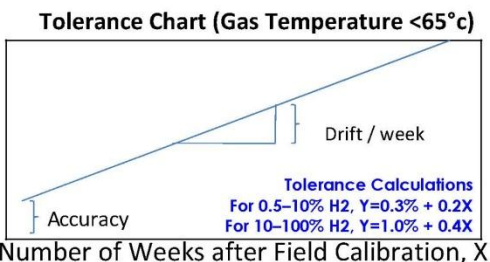


#### 4.4 Verification

##### Verification Interval

Verification is a process to compare the sensor output to a known hydrogen concentration. Verifications do not cause any wear on the sensor and can be accomplished as often as desired. The recommended interval to perform Verification depends solely on the user's desired tolerance for the specific application in question. If the user does not have a specific desired tolerance, H2scan recommends that Verification be performed every three months.

The tolerance (error) in measuring hydrogen has two primary components: the initial accuracy number (offset) and a weekly drift value (slope). The chart below is provided as a guideline for tolerance estimation for the HY-OPTIMA™ 700 and can be a useful tool in determining the initial verification frequency. The subsequent verification frequencies can be decided based on the actual weekly drift observed. The tolerance chart may be used in accordance with HY-OPTIMA™ 720, 730 and 740 accuracy specifications.



HY-OPTIMA™	Accuracy(*):	Drift/week:
700	± 0.3% absolute for 0.5 to 10% H2 ± 1.0% absolute for 10 to 100% H2	± 0.2% absolute for 0.5 to 10% H2 ± 0.4% absolute for 10 to 100% H2
730	± 0.15% absolute for 0.5 to 10% H2 ± 0.50% absolute for 10 to 100% H2	± 0.10% absolute for 0.5 to 10% H2 ± 0.20% absolute for 10 to 100% H2
740	± 0.15% absolute for 0.5 to 10% H2 ± 0.50% absolute for 10 to 100% H2	± 0.10% absolute for 0.5 to 10% H2 ± 0.20% absolute for 10 to 100% H2

\* Sensor performance specifications are only valid for units configured for a maximum 65°C dry process stream temperature. All figures assume pressure compensation, operating in ambient that do not contain Oxygen and are in addition to any errors in the gasses used. The accuracy is specified for serial port output only.

The drift chart can be used to determine the maximum recommended Verification interval to maintain a required level of accuracy. For instance, if a +/- 1% accuracy in a 5% H2/N2 gas is needed, a Verification should be typically performed every 3.5 weeks. If a +/- 2% accuracy is needed in the same gas, the recommended Verification interval can be extended to 8.5 weeks. Verifications may be done more frequently than these intervals if desired and should always be performed if the sensor readings are unusual or suspected to have large errors.

The HY-OPTIMA™ 700 Analyzer should be conditioned by operation in hydrogen exceeding 5% by volume until stable and taken through the Field Calibration, if exposed to oxygen or operated without hydrogen for an extended period. If the unit continues to exhibit errors in excess of the published accuracy specification and drift rate, please contact H2scan for factory evaluation and repair.



### Verification Procedure

Verification can only be accomplished through interface with the unit via the serial port (refer to the previous *Serial Communication Commands* section and the *LEVEL 1 COMMANDS* table in Section 3.3). Verification of sensor output should be conducted on a regular basis to insure proper unit operation. Analog outputs can be monitored through the user's system. As part of this sequence the date of verification is stored in the unit's memory.

**WARNING: IN ORDER FOR VERIFICATION TO SUCCESSFULLY TAKE PLACE, THE SENSOR MUST BE IN NORMAL RUNNING MODE.**

**Verification Using Serial Interface** – After establishing serial communication then follow the sequence below:

- 1) Press "**Esc**"
- 2) The unit will return the command prompt "**H2scan:**"
- 3) Type "**e**" then hit "**Enter**" and follow prompts to field verify sensor calibration at **two** gas concentrations

These steps will implement the following specification values as an example; **for values in bold, please substitute appropriate values relative to your specific operational conditions:**

- Local atmospheric pressure: **0.969 ATM**
- Hydrogen range: **0% to 30%** hydrogen, balance nitrogen
- Field Verification Gas #1: **1%** hydrogen, balance nitrogen (instead of gas #1 being 0% hydrogen, H2scan recommends Field Verification gases always have a hydrogen concentration)
- Field Verification Gas #2: **30%** hydrogen, balance nitrogen
- Settle Time: 30 minutes (H2scan recommends this duration for field verification)
- Tolerance of Field Verification Gas #1 (**1%** hydrogen by volume): For example,  $\pm 0.30\%$  absolute hydrogen by volume (refer to the *TOLERANCE CHART* above or enter user desired tolerance)  
NOTE: Poor accuracy of the verification gases will influence the achievable accuracy from the unit.
- Tolerance of Field Verification Gas #2 (**30%** hydrogen by volume):  $\pm 1.0\%$  absolute hydrogen by volume (refer to the *TOLERANCE CHART* above or enter user desired tolerance)



## 4.5 Calibration

### Calibration Interval

Calibration is used to correct any offset that exist between the sensor output and a known hydrogen concentration. Calibrations do not cause any wear on the sensor and can be accomplished as often as desired. It is recommended that Calibration be performed if a unit fails Verification.

### Calibration Procedure

**IMPORTANT NOTE:** During the Calibration process any previously completed Field Calibrations are cancelled. As a result, during the routine the unit may display a hydrogen concentration that is different from the applied gas concentration. This is normal. Once the procedure is completed, the readings will be corrected to display the right concentrations for all subsequent exposures.

Calibration can only be accomplished through interface with the unit via the serial port (refer to the previous *Serial Communication Commands* section and the *LEVEL 1 COMMANDS* table in Section 3.3). Analog outputs can be monitored through the user's system.

**Calibration Using Serial Interface** (firmware version 0.47) – Follow the sequence below:

- 1) Press "**Esc**"
- 2) The unit will return the command prompt "**H2scan:**"
- 3) Type "**f**" then hit "**Enter**" and follow prompts to field calibrate the sensor with **two** gas concentrations

These steps will implement the following specification values as an example; **for values in bold, please substitute appropriate values relative to your specific operational conditions:**

- Local atmospheric pressure: **0.969 ATM**
- Hydrogen range: **0% to 30%** hydrogen, balance nitrogen
- Field Verification Gas #1: **1%** hydrogen, balance nitrogen (instead of gas #1 being 0% hydrogen, H2scan recommends Field Verification gases always have a hydrogen concentration)
- Field Verification Gas #2: **30%** hydrogen, balance nitrogen
- Settle Time: 30 minutes (H2scan recommends this duration for field calibration)

**WARNING: AS IN THIS EXAMPLE, FOR OPTIMIZATION, THE HYDROGEN CONCENTRATIONS OF THE GASES IMPLEMENTED IN FIELD CALIBRATION AND FIELD VERIFICATION MUST BE THE SAME.**





FIELD CALIBRATION STEPS		
Step	Display	User response
1	H2scan:	Type "f" to run field calibration
2	Ready to Calibrate (Y/N)?	Type "y"
3	Pressure is 0.9690 atm (Y/N)?	Type "y" Please note that the firmware has remembered the atmospheric pressure from the preceding Verification procedure. Type "n" if a change is required and enter the correct pressure.
4	Save as default (Y/N)?	Type "n"
5	Gas1 is 0%H2 (Y/N)?	Type "n"
6	Gas1 for res (Y/N)?	Type "y"
7	Cal Gas: 2.000%H2 (Y/N)?	Type "n"
8	Enter gas:	Type "1" for gas #1, 1% hydrogen by volume
9	Cal Gas: 1.000%H2 (Y/N)?	Type "y"
10	Settle time: 3 min (Y/N)? n	Type "n"
11	Enter time:	Type "30" for a 30 minute duration for gas #1
12	Settle time: 30 min (Y/N)?	Type "y"
13	Apply 1.000%H2: Ready (Y/N)? y	Type "y"
Streaming data...		




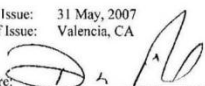
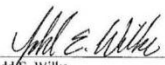
14	Taking Average... cap=0.00000 res=x.xxxxx	Calibration Gas #1 finished
15	Gas2 for res (Y/N)?	Type "y"
16	Cal Gas: 100.000%H2 (Y/N)?	Type "n"
17	Enter gas:	Type "30" for gas #2, 30% hydrogen by volume
18	Cal Gas: 30.000%H2 (Y/N)?	Type "y"
19	Settle time: 1 min (Y/N)?	Type "n"
20	Enter time:	Type "30" for a 30 minute duration for gas #2
21	Settle time: 30 min (Y/N)?	Type "y"
22	Apply 30.000%H2: Ready (Y/N)?	Type "y"
Streaming data...		
23	Taking Average... cap=0.00000 res=x.xxxxx	Calibration Gas #2 finished. Calibration complete.

- 4) Per H2scan's recommendation, upon completion of Calibration, conduct the Verification sequence as described in the previous section to verify that the calibration process was executed correctly.



## 5.0 Appendix

### 5.1 European Declaration of Conformity

		
<h2 style="margin: 0;">European Declaration of Conformity</h2> <p style="margin: 0;">Application of Council Directive: 2004/108/EC</p>		
<b>Standards to Which Conformity is Declared:</b>  Standards comply with requirements of the European Directives.	EN61326:1998 EN55011 Class A Group 1 EN61000-4-2 EN61000-4-3 EN61000-4-4 EN61000-4-5 EN61000-4-6 EN61000-4-11 EN61000-3-2:2001 EN61000-3-3:2000	
<b>Manufacturer's Name:</b>	H2scan Corporation	
<b>Manufacturer's Address:</b>	28486 Westinghouse Place, Suite 100 Valencia, CA 91355 (661) 775 - 9575	
<b>Equipment Description:</b>	Hydrogen Monitors	
<b>Equipment Class:</b>	Laboratory, Measurement, and Process Control Equipment: Normal Environment	
<b>Model Numbers:</b>	600 and 700	
The tests were carried out by the test laboratories of DNB Engineering and/or in accredited testing laboratories. Test reports may be inspected on demand.		
<i>We, the undersigned, hereby declare that the equipment specified above conforms to the above Directive(s) and Standard(s).</i>		
Date of Issue: 31 May, 2007 Place of Issue: Valencia, CA  Signature:  Full Name: Dennis Wayne Reid Position: Chief Executive Officer	Signature:  Full Name: Todd E. Wilke Position: Chief Technical Officer	
<small>Annexes are part of this declaration. This declaration certifies conformance with the above mentioned Directives.          Affirmation of attributes in a legal sense is not included. Security declarations given in the product documentation have to be considered.</small>		
<small>28486 Westinghouse Place, Ste.100, Valencia, CA 91355          Tel: 1-661-775-9575, Fax: 1-661-775-9515</small>		



QUESTIONS?  
PLEASE CONTACT US AT:



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Valencia, California 91355, U.S.A.  
Tel: (661) 775-9575 / Fax: (661) 775-9515  
E-mail: [sales@h2scan.com](mailto:sales@h2scan.com)  
Website: <http://www.h2scan.com>

Manual copyright © 2007, H2scan  
Instrument software copyright © 2007, H2scan  
Wide Range Sensor™ protected under US patent number 5,279,795



## IMPORTANT NOTICES

<p>Read and understand this operating manual before installing or using the unit.</p>	
	<p>Only use cables from H2scan with this unit.</p> <p>If this equipment is used in a manner not specified by H2scan, the protection provided by this equipment may be impaired.</p>
	<p>Hydrogen is flammable at 4% in air. Take indications seriously and be prepared to take action. In the event of detection of 4% or higher of a hydrogen gas concentration there is a high probability of a hazard to safety. Inform local emergency response personnel immediately.</p>
<h3 style="text-align: center;"><u>LIMITATION OF LIABILITY</u></h3> <p>In the event of a defect in a product, h2scan shall not be responsible for any direct, indirect, incidental or consequential damages resulting therefore, including, but not limited to, loss of revenue and/or profit.</p>	

## LIMITED WARRANTY

H2scan Limited Warranty: Each hydrogen instrument ("Product") will conform, as to all substantial operational features, to the Product specifications set forth in this Manual and will be free of defects which substantially affect such Product's performance for twelve (12) months from the ship date for such Product.

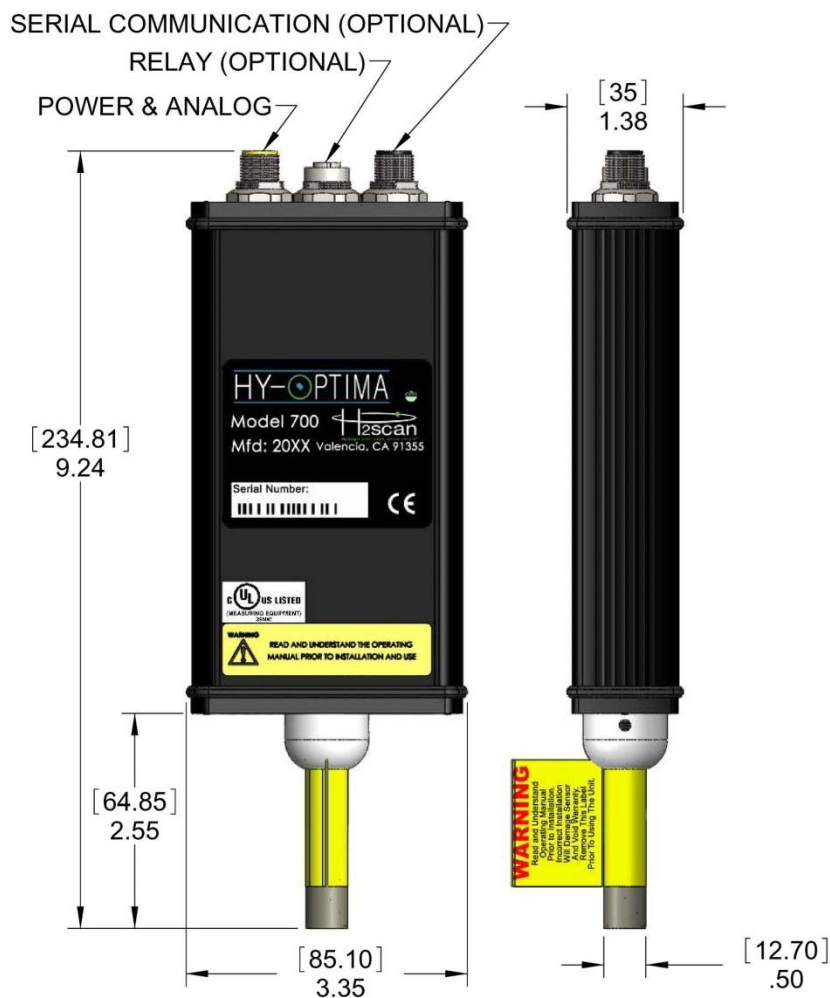
Must Provide Notice of Defect: If you believe a Product that you believe is defective, you must notify H2scan in writing, within ten (10) days of receipt of such Product, of your claim regarding any such defect.

Return Product to H2scan for Repair, Replacement or Credit. If the Product is found defective by H2scan, H2scan's sole obligation under this warranty is to either (i) repair the Product, (ii) replace the Product, or (iii) issue a credit for the purchase price for such Product, the particular remedy to be determined [by H2scan] on a case-by-case basis.

Voided Warranty. H2scan's 12 Month Limited Warranty is void for any of the following:

- The unit is opened and the manufacturing seal is broken
- Unauthorized repair work performed at the customer's location or carried out by anyone other than H2scan's factory trained technicians
- Equipment or parts that have been tampered with, misused, neglected, mishandled, improperly adjusted, or modified in any way without the written consent of H2scan.
- Equipment or parts that have been damaged due to shipping, misuse, accidents, mishandling, neglect, or problems with electrical power sources.
- Repair work performed during the warranty period does not prolong the warranty period past the original period.
- System operation in incorrect or inappropriate environments.
- Usage that is not in accordance with system guidelines or an operator's failure to follow manual instructions.

Limitation of Warranty: THE ABOVE IS A LIMITED WARRANTY AS IT IS THE ONLY WARRANTY MADE BY H2SCAN. H2SCAN MAKES NO OTHER WARRANTY EXPRESS OR IMPLIED AND EXPRESSLY EXCLUDES ALL WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. YOUR SOLE REMEDY HEREUNDER IS REPAIR OR REPLACEMENT OF THE PRODUCT OR A CREDIT FOR THE PURCHASE PRICE FOR SUCH PRODUCT, THE PARTICULAR REMEDY TO BE DETERMINED BY H2SCAN ON A CASE-BY-CASE BASIS. H2SCAN SHALL HAVE NO LIABILITY WITH RESPECT TO ITS OBLIGATIONS UNDER THIS AGREEMENT FOR CONSEQUENTIAL, EXEMPLARY, OR INCIDENTAL DAMAGES EVEN IF IT HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. THE STATED EXPRESS WARRANTY IS IN LIEU OF ALL LIABILITIES OR OBLIGATIONS OF H2SCAN FOR DAMAGES ARISING OUT OF OR IN CONNECTION WITH THE DELIVERY, USE OR PERFORMANCE OF THE PRODUCTS.



## 2.0 Operation

### 2.1 Unit Location

The unit can be mounted in any orientation or position, however vertical mounting (unit above process connection) should be made in process streams containing liquids or potentially condensing gases.

#### 2.1.1 Warning Label

Remove sensor tube warning label prior to using the unit.



## 2.2 Mounting

Mounting is achieved by securing the sensor tube into the supplied fitting directly in the process piping as shown below. Optional mounting brackets that attach to the instrument housing are also available.

**WARNING: DO NOT CINCH DOWN OR TIGHTEN FERRULES OUTSIDE OF THE FERRULE REGION OF THE LONG TUBE OR YOU WILL RISK PERMANENTLY DAMAGING THE LONG TUBE AND SENSOR ASSEMBLY WITHIN.**

1.0 inches is the maximum distance that the fitting mount can be from the end plate of the HY-OPTIMA™ 700 unit. This is referred to as the Ferrule Region of the long tube which has a wall thickness of 0.065 in. Any distance exceeding 1.0 in. will be in the Sensor Assembly Region where the tube wall thickness is only 0.038 in. Cinching down a fitting outside the Ferrule Region and in the Sensor Assembly Region may result in permanent damage to the long tube and the sensor assembly within.



## 2.3 Process Connection

H2scan offers a variety of fittings to mate the unit to a process stream. The following table lists our standard fitting selections. Others are available upon request.

- ½ in. MNPT thread
- ½ in. FNPT thread
- -8 SAE/MS thread size
- ... and many other industry standards.

## 2.4 Startup

Power (8 to 13 VDC) is connected via the Power/Analog connector as shown in Section 3.1. Once power is applied, the unit executes a warm-up sequence lasting **five minutes**. The status LED will be amber in color during the warm-up sequence. When the unit is ready for operation, the status LED will change to green (if the measured hydrogen concentration is under the first relay set point) and to red (if it exceeds the second relay set point). The following operations will be completed in this warm-up sequence:

- Heat the sensor to operating temperature
- Perform system self-test



## APPENDIX C

## PX1005 MANUAL

# THIN-FILM CRYOGENIC PRESSURE TRANSDUCER

## PX1005 Series

mV/V Output

0-15 to 0-1000 psi

0-1 to 0-70 bar

1 bar = 14.5 psi

1 kg/cm<sup>2</sup> = 14.22 psi

1 atmosphere = 14.7 psi = 29.93

inHg = 760.2 mmHg = 1.014 bar

All Ranges  
**\$1500**



- ✓ High Performance
- ✓ High Reliability
- ✓ 0.1% Stability for 18 Months
- ✓ Operates From -196 to 149°C (-320 to 300°F)
- ✓ Exceptional Calibration Stability

OMEGA's PX1005 sputtered thin-film pressure transducer was designed for cryogenic service; it can operate in temperatures from -196 to 149°C (-320 to 300°F). Yet, even in these extreme temperatures, it provides outstanding accuracy, long-term calibration stability, and reliability.

Static accuracy is  $\pm 0.25\%$ , and thermal zero and sensitivity shifts over the compensated range of -196 to 27°C (-320 to 80°F) are less than  $\pm 0.01\%/^{\circ}\text{F}$ . The all-welded stainless steel pressure cavity and double-isolated case ensure reliability in the inherently tough environments of cryogenic service.

OMEGA's thin-film technology makes this premium performance possible. The strain gages are sputter-deposited, forming a molecular bond with the substrate. There is virtually no shift, drift, or creep to cause the transducer's calibration to change.



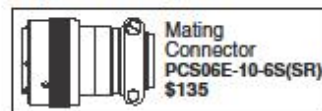
Shown larger than actual size.

PX1005L1-1KAV, \$1500, shown actual size.

## Applications

- ✓ Liquid-Fuel Engines and Test Stands
- ✓ Launch System Ground Support Equipment
- ✓ Space Systems
- ✓ Cryogenic Process Instrumentation Tested to -196°C (-320°F)

OMEGA's PX1005 is available in many standard ranges from 15 psi to 1000 psi. A calibration record is supplied with every unit.



Mating Connector  
PCS06E-10-6S(SR)  
\$135

## MOST POPULAR MODELS HIGHLIGHTED!

### To Order (Specify Model Number)

Models with mV/V Output and Bendix Connector

RANGE	MODEL NO.	PRICE	COMPATIBLE METERS*
<b>Absolute Pressure (All Ranges Available in Sealed Gage Pressure)</b>			
0 to 15 psi    0 to 1.0 bar	PX1005L1-015AV	\$1500	DP41-S, DP25B-S
0 to 25 psi    0 to 1.7 bar	PX1005L1-025AV	1500	DP41-S, DP25B-S
0 to 50 psi    0 to 3.4 bar	PX1005L1-050AV	1500	DP41-S, DP25B-S
0 to 100 psi    0 to 6.9 bar	PX1005L1-100AV	1500	DP41-S, DP25B-S
0 to 250 psi    0 to 17.2 bar	PX1005L1-250AV	1500	DP41-S, DP25B-S
0 to 500 psi    0 to 34.5 bar	PX1005L1-500AV	1500	DP41-S, DP25B-S
0 to 1000 psi    0 to 68.9 bar	PX1005L1-1KAV	1500	DP41-S, DP25B-S

Comes complete with 5-point calibration.

\* See section D for compatible meters.

Metric ranges available - Consult Engineering.

To order sealed gage pressure, replace "A" in model number with "S" (no extra charge).

Ordering Examples: PX1005L1-100AV, 100 psi absolute pressure transducer, with

MS3365B-4 male pressure connection and integral electrical connector, \$1500.

PCS06E-10-6S(SR), mating connector (sold separately), \$135.

PX1005L1-1KSV, 1000 psi sealed gage pressure transducer with MS3365B-4 male pressure connection and integral electrical connector, \$1500. PCS06E-10-6S(SR), mating connector (sold separately), \$135.

### ACCESSORY

MODEL NO.	PRICE	DESCRIPTION
PCS06E-10-6S(SR)	\$135	Mating connector for PX1005 transducers



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